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A Plan for Testing Perpetual Forest Survey on the Allegheny National Forest

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O.D.C. 52

A PLAN FOR TESTING PERPETUAL FOREST SURVEY ON THE ALLEGHENY NATIONAL FOREST

by

C. Allen Bickford

I. INTRODUCTION

Administration of our national forests has been based on management plans that are revised about every ten years. Data required by these management plan revisions have been supplied by conventional cruising in most instances. Ten years ago a new approach was tried on the Allegheny National Forest when the job was combined with the Forest Survey. That cooperation provided adequate inventory data as to amount of timber but failed to tell where the Forest could make a timber sale.

Other schemes have also been developed: Sump and others developed a system that has been used in Region Nine. This procedure delineates forest type, stand-size class, and density class on aerial photographs as a basis for stratified sampling. Osborne has described a method for continuous inventory that could be used on the national forests. Grosenbaugh has adapted the relascope to American conditions and explored its application in southern forests. Stott has pioneered a procedure called "Continuous Forest Inventory" which uses punched card machines and mark sensing to streamline computational procedure (and the method has been vigorously

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promoted by IBM as a new field for their machines). And the Forest Survey has developed methods for more efficient cruising. Undoubtedly the most significant feature has been the combined use of aerial photographs and modern sampling methods.

Two distinct uses have been made of aerial photographs: delineation of classes of area and classification of a series of points or plots. Complete delineation of a forest property has two very real advantages--it tells the forest manager where his timber lies and secondly, such delineation means there is no sampling error, so far as delineated area data are concerned. There may be errors of classification, of course, but these are not sampling errors. The principal drawback to complete delineation is that it is costly. Cost of delineation may be reduced by using fewer classes or a larger minimum area to delineate. This also tends to increase variance within classes, however, and may not reduce total cost.

Classification of a series of photo plots is the method used by Forest Survey in the Northeast. Where no attempt is made to show location of timber, this method, together with double or triple sampling, appears to be the most efficient procedure for estimating total volume of timber. This is true because aerial photographs provide the cheapest means of stratification, especially when based on plots, and because there is less variation between ground plots in the same strata.

Modern sampling methods in forest cruising, usually means some form of stratified random sampling. Its efficiency depends on significant differences in mean volumes by strata and such differences are not difficult to obtain from classes identified on aerial photographs. Of course, with increasing age of photography, growth and cutting tend to reduce the significance of these differences. In extreme cases, there might be no gain from stratified sampling. Where significant differences do exist, two methods are available for choosing numbers of plots by strata: optimum allocation and proportional sampling. The former is appropriate in simple situations where there are significant differences between classes in the variance, or the standard deviation. Forest Survey in the Northeast has used optimum allocation, in spite of a complex set up, to take advantage of the greater efficiency in estimating volume in cubic feet because the other required data have had less exacting standards of accuracy.

The method, described below, is an attempt to combine use of aerial photographs and stratified sampling to obtain data required by scientific forest management as efficiently as our current knowledge permits. It combines delineation and point classification. It would be coordinated with Forest Survey, tying into their design and using their photo interpretation. It would be done on an annual basis rather than periodically as in the past. The method would also provide the data needed for the 1958 revision of the management plan and lay the basis for superior data when the 1968 revision is made.

II. THE METHOD PROPOSED

The method proposed, in brief, amounts to this:

1. Delineation of stand-size classes on aerial photographs.
2. Use Forest Survey photo plots to substratify these area classes.
3. Remeasure Forest Survey ground plots to obtain growth data.
4. Establish new plots, as needed, to obtain inventory volume to desired accuracy.
5. Summarize data using punched card machines.
6. Prepare required revision of the management plan.

Now let's look at these various steps in more detail.

1. Delineation.

Delineation of stand-size classes on the aerial photographs is the first step. It is done to provide the forest manager with information regarding the location of his timber. It is expected to make it easier for him to find timber sale chances.

The aerial photographs would be studied under a stereoscope, supplemented by ground checking, and lines would be drawn to show four kinds of forested areas:

a. Sawtimber is a stand from which a sawtimber sale could be made. It is expected to have a minimum stand of about 2000 board feet per acre, of which about 1000 board feet per acre could be marked for cutting. Volumes are based on all trees 11 inches DBH and larger.

b. Heavy Poles is a stand from which a pulpwood sale could be made. The wood might be used for another purpose but the common demand for this class of material is pulpwood. Such stands are expected to have a minimum volume of 1720 cubic feet (20 cords) per acre, of which at least 600 cubic feet (7 cords) could be marked for cutting in trees 5 inches DBH and larger. Such stands may have in addition to the minimum 7 cords per acre something less than 1000 board feet per acre in trees 11 inches DBH and larger.

c. Light Poles, Saplings, Seedlings is a stand from which no cut of pulpwood or sawtimber is available and volumes and/or tree sizes are lower than the minimum specified for sawtimber and heavy poles, but crown density is over 40 percent.

d. Denuded and Poorly Stocked includes open areas and stands having less than 40 percent crown density. In general, the areas need special treatment, such as planting, cultural work, or a combination of stand removal and planting to desirable species. The "orchard" type falls in this category.

In making these delineations, certain minimum areas should be observed. They are determined from the likely action of a forest manager. For this national forest, only one consideration seemed pertinent: is the area large enough to make a sale? On this basis the minimum area to delineate for all classes is ten acres.

It is recognized that growth, cutting, fire, etc., over the years will make these delineations obsolete. To overcome this problem it is proposed to obtain new photographs every ten years, or so, and redelineate classes of area. In the meantime changes due to growth will be neglected while the others would, of course, be a matter of record.

When the delineation of photographs is complete, the information will be transcribed to a planimetric map of the forest. Areas by classes will be determined from this map using a planimeter. Delineation is done from studying all the forested area and has no sampling error. There will be other errors, however, from misreading photographic images and perhaps are mistakes rather than errors. They should be kept to a reasonable minimum and some ground checking should be made to be sure the delineations mean what was intended. There should be no need to be meticulous, however, as confusion can result.

2. Use Forest Survey Photo Plots.

The Forest Survey interpreted about 1,500 photo plots on the National Forest in 1954. Each plot was given an estimated photo volume class and these classes defined the strata for sampling. It is proposed to use these same photo plots to substratify the delineated stand-size classes. This will require showing both photo plots and delineations on the same base to be able to calculate proportions by photo volume class for each class of stand size. The 1950 photographs are suggested as the common base.

It will also be necessary to locate the ground plots established in 1947 on the 1950 photographs and determine their photo volume class. This would be done by Forest Survey in Upper Darby. Photo plots should be distributed in accordance with proportional sampling, all over the National Forest. About every ten years, as new photographs become available, the Forest Survey expects to reinterpret the same photo plots. Thus the required information should continue to be available to the National Forest as there is need to revise management plans.

3. Remeasure Forest Survey Plots.

Scientific forest management usually relates allowable cut to current growth. In applying this principle to the Allegheny National Forest, an estimate of growth is required for the whole forest although timber sales will come only from areas classed as merchantable. An allowable sampling error of 10 percent ($P = 0.95$) was set for this estimate of growth.

Preliminary claculations using data from the 37 plots remeasured in 1954, in formula 8 of appendix, indicated that approximately 140 plots should be remeasured to meet this goal. As there were not that many plots available, it was agreed at our meeting in Warren, April 1956, that the Allegheny National Forest would remeasure all remaining plots established in 1947 and not remeasured (see my memorandum of May 1, 1956, RS-NE, MENSURATION, Stand Studies, Perpetual Forest Survey). The

1947 survey consisted of 124 ground plots of which about 10 percent are now lost for various reasons. At this writing 76 plots remain to be remeasured. In the future this number would be calculated, using previous experience, as the number estimated necessary to meet the specified accuracy.

These plots would serve to estimate periodic growth, either as a simple arithmetic average of all plots or as a series of averages by classes. Method of presentation would be determined by tests of significance of differences in mean growth between photo volume classes and stand-size classes.

These plots would also provide the data needed to determine the regression of current volume on initial volume and other factors, used to adjust older data to the present. In this first application, no regression would be needed as we plan to remeasure all of the plots established by Forest Survey in 1947. The first remeasurement must be completed during 1957. And we expect to complete the job by April 1, 1957. Later approximately one tenth of the permanent plots would be remeasured each year. During a period of transition, the arrangement will be more complex.

Remeasurement of a plot consists of relocating it as exactly as circumstances permit and tallying trees by species and d.b.h. in much

the same manner as was done at establishment. It is evident the center must be relocated within about a foot of its original position to obtain the expected benefits of a remeasured plot. Where there has been cutting during the period, stumps should be tallied by species, stump height, and stump diameter.

Living trees are tallied by species and d.b.h., as usual, and in addition are separated into cut and leave in accordance with standard timber sales practice on the National Forest.

Before leaving the plot, the retally should be compared with the original to be sure that periodic change is reasonable. Each tree of the former tally should be accounted for as a survivor, stump, or dead tree. Ingrowth is usually limited to the smallest diameter class. Any conflict should be checked on the spot to be sure the tree is on or off the plot and that species and d.b.h. agree with the tree on the plot. The man on the plot is in a much stronger position to resolve such disagreements than someone in Warren or Upper Darby.

4. Establish New Plots.

The forest manager needs to know what he has as well as knowing how it is changing. The allowable error has been set at 10 percent ($P = 0.95$) for this quantity too. Now the most efficient way to estimate current volume, using the data already available, is by a weighted

average of adjusted 1947 volume and a direct estimate of current volume (see below). Formulae of the appendix show exactly how this weighting is accomplished and formula 9 provides an estimate of the number of new ground plots required to meet a specified accuracy in inventory volume. In this formula, proportions are supplied by the photo interpretation that has been done by Forest Survey and their experience would provide estimates of the strata means and variances. The accuracy required of the second estimate, which is the first term in the denominator of formula 9, is given by formula 7 and is determined by the variance of the first estimate and the accuracy needed in inventory volume. Thus it may be seen that the number of new plots required depends on the means and variances by strata as recognized in 1947 and 1954, numbers of ground and photo plots used in 1947, and the number of photo plots interpreted by Forest Survey in 1954, as well as the specified allowable error. Preliminary calculations suggest that the number needed is slightly greater than the number of plots estimated as necessary for remeasurement.

When all the scheduled plots have been remeasured some time this winter, and the data worked up, number of plots needed, according to formula 9 will be calculated. We hope to have the remeasured data summarized by May 1, 1957 and numbers of new plots needed computed early enough to allow establishment of new plots in the field by September 1, 1957.

These new plots would be drawn from the photo plots interpreted in 1954 on photographs taken in 1950. Then distribution by strata should be made by proportional sampling (see formula 10) to simplify later expansion factors. For the 1958 management plan revision, all new plots should be established before September 1, 1957. Thereafter, new plot establishment would be equalized throughout the ten year period. Trees on these plots would be tallied in the same manner as those on remeasured plots as regards species, d.b.h., and marked class. Dead trees of merchantable size and species would be distinctively marked to assure accurate determination of periodic mortality.

Mistakes in delineation and photo interpretation are certain to occur. Their general effect is to increase variability within a class which means more plots are required to meet the accuracy standard and costs of survey are increased proportionately. Every effort should be made to minimize the occurrence of these mistakes.

5. Summarize Data.

As the field data are completed, they will be forwarded to the Station for processing. After editing, as much of the data as possible will be entered on punched cards for ease of subsequent operations. Planimetered areas by merchantability classes are converted to acres when multiplied by the appropriate factor. Proportions by photo volume classes will be obtained from numbers of photo plots and converted to

areas in acres. These area data will be summarized by photo volume class and merchantability class by ranger districts and counties and for the whole national forest.

Growth will be estimated using data from remeasured plots. Periodic net growth for a plot is volume when remeasured minus volume when established where volume is to the same standards, using the same volume table. Where there has been cutting, estimated volume of trees cut[1/] should be added to volume of trees measured at the end of the period. The data may be separated into accretion, ingrowth, mortality, and timber cut. Growth data so obtained will be analyzed for possible correlation or stratification and reported accordingly. Possible independent variables include merchantability class, photo volume class, site quality, and initial volume or basal area. This analysis should lead to an average, or a series of them, of net growth per acre per year, or per decade. From these averages, annual growth for the Forest would be estimated as a guide in the determination of the allowable annual cut.

Estimation of total current volume is more complex. It is the weighted average of two independent estimates (see formula 1): The first is simply the 1947 data brought up to date while the second is

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1/ It should be noted that this adjustment provides for the inclusion of growth on cut trees from initial measurement to time of cutting, in the net periodic growth of a plot.

estimated from new photography, new strata, and new ground plots.

The first estimate is based on 1947 photo stratification and the later volume of remeasured plots, adjusted to January 1958. This adjustment will include provision to remove effects of cutting as well as to add growth as needed to obtain 1958 volume. Added growth is average for the class times number of growing seasons that will have occurred since remeasurement. Each plot volume is an observed Y_{ij} from which the first estimate is obtained using formula 2. Note that the formula estimates 1958 volume plus periodic timber cut. This last element should be determined from National Forest records and deducted to obtain the first estimate of 1958 volume.

The second estimate is based on the 1954 photo volume stratification, the 1955-1956 delineations of merchantability class, and the new plots established in 1957. Total volume will be estimated using formula 3. With proportional sampling there is a single factor to multiply by each tree or plot volume so that the sum of the products is total estimated volume in 1958. No adjustment for growth or cutting is required. Data of this estimate will be used to distribute weighted total volume by the same classes as named above for area data.

Weighted total volume will be estimated using formula 1, where the required variances are calculated using formulae 4 and 5. There

is no sampling error of timber cut, used to obtain total volume under the first estimate, and the sampling errors of growth and conversion from stump measurement are neglected in computing the variance of the first estimate of current volume.

Volume available for sale may vary with stand merchantability and photo volume class. Its total may be estimated, however, using the same factor as will be used to obtain the second estimate of total volume. Averages by classes of area should be computed for possible use by the Forest Supervisor or his staff.

The same expansion factor may be used to determine numbers of trees on the Forest by species and d.b.h. for possible use in determining d'Liocourt's quotient.

6. Prepare Required Revision of the Management Plan.

A management plan includes estimates of the amount of growing stock present and current average annual growth, and suggests an allowable cut. On the basis of these data, a schedule of proposed cuts is developed for the decade ahead.

Basic definitions and objectives are left to the Forest Supervisor and his staff. We hope they will explore the possible use of d'Liocourt's quotient as a means of projecting the current stand and indicating how it should be cut. H. Arthur Meyer's article on stand

structure should be carefully studied as a prelude to trying out this "q". There are two promising possibilities: (1) for the forest as a whole, and (2) for individual stands where an all-aged structure is desired. In either case, "q" is a guide or index for distributing the cut and shaping the stand. For larger areas it might be useful with even-aged stands in place of or as a supplement to area regulation.

7. The Future.

As soon as the data needed for the 1958 revision are complete, plans should be prepared for obtaining the data needed for the 1968 revision. The sampling design and computational procedure will be different because only part of the plots measured in 1954, 1956, and 1957 are expected to be remeasured. Thus regression will be used in adjusting earlier volumes to 1968, which should increase the complexity of formulae and computations and may reduce the number of plots required. We shall certainly have a stronger basis for calculating numbers of plots and should know better how to go about it.

The revised sampling design will include a transition schedule to obtain the data needed for the 1968 revision and should attempt to describe a fixed program thereafter. This design will also include description of the appropriate computational procedures needed to provide the required data on growth and inventory. It is hoped this revised sampling procedure can be specified enough to begin remeasuring

plots in 1958 and to be ready to use new aerial photographs as soon as they are available. As soon as the size of the field job is known, plots should be selected and a schedule worked out showing numbers of plots to establish and to remeasure by years and ranger districts. All plots established or remeasured after 1956 should be selected using proportional sampling to simplify computational procedure and to avoid the possible pitfalls of optimum allocation in complex situations.

Formulae Needed to Apply Perpetual Forest Survey to the Allegheny National Forest

1. Weighted total volume:

$$T = \frac{S^2_{\bar{y}_1} T_2 + S^2_{\bar{y}_2} T_1}{S^2_{\bar{y}_1} + S^2_{\bar{y}_2}}$$

Where T is weighted total volume; T_1 is first estimate of total volume; T_2 is second estimate of total volume; $S^2_{\bar{y}_1}$ is the variance of mean volume per acre according to T_1; and $S^2_{\bar{y}_2}$ is the corresponding parameter of T_2.

2. First estimate of total volume:

$$T_1 + \text{periodic timber cut} = A\bar{Y}_1 = A\sum p_{1i}\bar{Y}_{1i} = A(p_{11}\bar{Y}_{11} + p_{12}\bar{Y}_{12} + \ldots + p_{1k}\bar{Y}_{1k})$$

Where A is total forest area; $\bar{Y}_1$ is mean volume per acre at first estimate without adjustment for cut; p_{1i} is proportion of forest area in $i^{\underline{th}}$ stratum at first estimate; $\bar{Y}_{1i}$ is corresponding mean volume per acre.

3. Second estimate of total volume:

$$T_2 = A\bar{Y}_2 = A\sum p_{2i}\bar{Y}_{2i} = A(p_{21}\bar{Y}_{21} + p_{22}\bar{Y}_{22} + \ldots p_{2k}\bar{Y}_{2k})$$

Where symbols are defined as above with obvious modifications.

4. Variance of the first estimate:

$S^2_{T_1} = A^2 S^2_{\overline{Y}_1} + \overline{Y}^2_1 S^2_A + S^2_{\text{Timber cut}}$ but $S^2_A = 0$ and if timber cut is obtained from Forest records $S^2_{\text{Timber cut}}$ is also zero.

Whence $S^2_{T_1} = A^2 S^2_{\overline{Y}_1} = \left\{ \frac{(\Sigma p_{1i} s_{1i})^2}{h} + \frac{\Sigma p_{1i} (\overline{Y}_{1i} - \overline{Y}_1)^2}{H} \right\} A^2$

Where S_{1i} is standard deviation of $i^{\underline{th}}$ stratum; h is number of original ground plots; and H is number of photo plots used in 1947 on the National Forest.

5. Variance of the second estimate:

$$S^2_{T_2} = S^2_{\overline{Y}_2} = \frac{\Sigma p_{2i} S^2_{2i}}{n} + \frac{\Sigma p_{2i} \left(\overline{Y}_{2i} - \overline{Y}_2\right)^2}{N}$$

Where S_{2i} is standard deviation of $i^{\underline{th}}$ stratum; n is number of new ground plots; and N is number of photo plots used in 1954 on the National Forest.

6. Variance of weighted total volume:

$$S^2_T = A^2 S^2_{\overline{Y}} = A^2 \frac{S^2_{\overline{Y}_1} S^2_{\overline{Y}_2}}{S^2_{\overline{Y}_1} + S^2_{\overline{Y}_2}}$$

All symbols previously defined.

7. Variance required of second estimate:

$$S^2_{\overline{Y}_2} = \frac{S^2_{\overline{Y}_1} S^2_{\overline{Y}}}{S^2_{\overline{Y}_1} - S^2_{\overline{Y}}}$$

8. Number of remeasured ground plots:

$$m = \frac{c^2 t^2}{e^2}$$

Where m is number of plots; c is coefficient of variation of net growth; and e is desired accuracy in percent.

9. Number of new ground plots (proportional sample):

$$n = \frac{\sum p_{2i} s_{2i}^2}{(s_{\bar{Y}_2}^2)_A - \frac{\sum P_{2i}(\bar{X}_{2i} - \bar{X}_2)^2}{N}}$$

Where $(s_{\bar{Y}_2}^2)_A$ is the square of allowable error in $\bar{Y}_2$ to achieve a specified accuracy in $\bar{Y}$ or T.

10. Number of new ground plots in $i^{\underline{th}}$ stratum (prop. sample):

$$n_i = p_i N$$

General Standards for Timber Survey

Allegheny National Forest - 1956 & 1957

Stand Size Classes

Minimum mapping unit 10 acres

Sawtimber (Code 1)	- A minimum of 2000 bd.ft. net volume per acre, furnishing a minimum cut of 1000 bd.ft. per acre.
Heavy Poles (Code 2)	- Less than 2000 bd.ft. per acre of sawlogs, but a minimum of 20 cords of cordwood per acre - furnishing a cut of less than 1000 bd.ft. or a minimum of 7 cords per acre. Cord - 4x4x8 rough wood
Seedlings, Saplings, Light Poles (Code 3)	- 40% density of stocking to 20 cords per acre
Open (Code 4)	- Denuded to 40% density. Include all "orchard" areas which have no potential sawlog quality.

Tree Merchantability

a. Sawlog Trees - All hardwoods 11.0 inches DBH and larger and all softwoods 9.0 inches DBH and larger. 30% or more of gross volume merchantable for sawlogs

b. Pulpwood - 3 or more 48 inch sticks per tree

Log or Bolt Merchantability

a. Sawlogs - Minimum length 8 feet. Minimum d.i.b. 10 inches for hardwood and 8 inches for softwoods. Scale 33-1/3% of gross scale for black cherry and sugar maple and 50% for all other species.

b. Pulpwood - Minimum d.i.b. 4 inches. Minimum length 4 feet. Splitwood acceptable. Sticks must be reasonably straight, free of rot and not excessively knotty.

Code for Form 22

Photo Proj.	- Enter either APL, APM, APK, APJ, APH, depending on specific photo.
Print No.	- Enter picture number such as 88-50 or 71-83.
Comp.	- Immediately after Comp. enter 9N, 10S, etc., as indicated on Compartment map.
PHO	- Leave blank
Plot	- Enter plot number in box
Elev.	- Enter in hundreds of ft. such as 12, 20, etc.
Aspect	- Enter compass bearing after Aspect

Code		Code	
North	- 1	South	- 5
Northeast	- 2	Southwest	- 6
East	- 3	West	- 7
Southeast	- 4	Northwest	- 8

Slope % - Enter abney reading immediately after %.

Code		Code	
0 - 5%	- 1	25.1 - 30%	- 6
5.1 - 10%	- 2	30.1 - 35%	- 7
10.1 - 15%	- 3	35.1 - 40%	- 8
15.1 - 20%	- 4	40.1 - 45%	- 9
20.1 - 25%	- 5	45.1 - 50%	- 10

Soil Class - Based on parent material

Code

1. Alluvium
2. Homewood
3. Mercer
4. Pottsville-Pocono   Sandstones & conglomerates
5. Devonian shales

% Sand - To be determined in office from soil samples
Enter to nearest 5%.

% Silt-Clay - To be determined in office from soil samples
Enter to nearest 5%.

Plot Location - position on slope.

	Code
Stream bottom	- 1
Lower third	- 2
Middle third	- 3
Upper third	- 4
Ridge or ridge flat	- 5

Area Merchantability

	Code
Sawtimber	- 1
Heavy Poles	- 2
Light poles, Saplings & Seedlings	- 3
Denuded & Poorly Stocked	- 4

Ave. Site Index - Enter to nearest 10 ft.

Water Table - Enter inches to mottled zone indicating upper level of water table during wet periods of year

Podsol Horizon - Enter inches of gray A horizon

CD (Cause of Death) Dead Tree Block

1. Logging
2. Wind throw
3. Suppression
4. Lightning
5. Fire
6. Insects
7. Disease
8. Unknown
9. Animal

Cut & Leave -

Cut - 1
Leave - 3

Vigor Class -

1 - Crowns of trees are large, dense, of good color, with space for rapid growth. Usually dominant. Codominant trees qualify if they possess above tree characteristics.
2 - Trees have less than full crowns in width and length, slower growth, less dense. Usually codominant. Some overtopped trees (mostly tolerant species).
3 - Trees with spindly or one sided crowns, scanty foliage, crown injuries. Usually overtopped trees plus very poor dominants and codominants.
4 - Trees growing under obvious handicaps - severe suppression, injury, old age.

Measurement of Sample Plots and
Use of Form 22 (Plot Tally Sheet)
For Remeasurement of 1947 Field Plots
and New Plots to be Established in 1957
Allegheny National Forest

1947 plots are 0.5 acre in size. For plot remeasurement use one tally sheet for 0.2 acre and a second sheet for tally on remaining 0.3 acre (outside 0.2 acre). Tally on 0.3 acre will be sawtimber trees exclusively. Subdividing the tally thusly is to make it possible to convert existing plots to a perpetual inventory system based on a 0.2 acre plot.

a. Size of Plot
   Tally all trees 5.0" to 10.9 DBH on 0.1 acre - plot radius 37.2 ft. or 56.4 links
   Sample-pole measurements will be taken on trees 5.0 to 10.9" DBH which are not more than 4D in links (D being DBH in inches) or 2.64D in feet from plot center
   Tally all trees 11.0 inches DBH and larger on 0.2 acre plot - radius 79.8 links or 52.7 ft. On a supplemental sheet tally similar size trees on 0.3 acre plot which is that part of 0.5 acre plot between radius of 126 links (83.3 ft.) and 79.8 links (52.7 ft.)

b. Re-establish or establish plot center with studded T iron fence post or equivalent.

c. Measure trees clockwise, starting from a north compass bearing

d. Measure DBH of all trees with diameter tape on uphill side. The measurement must be made as accurately as possible at 4.5 ft. mark. If so instructed, mark DBH point with paint

e. Measure all merchantable sawtimber heights and pulpwood in upper stem with an appropriate instrument as needed. Pulpwood sticks in the other parts of the tree must be estimated ocularly in all instances.

f. Trees on boundary of 0.2 acre or 0.1 acre plot will be counted "in" if required plot radius can be measured from center of tree at stump height to plot center. Trees on the plot boundary and "in" will be bark scribed facing plot center.

g. Forked Trees
   1. If main stem will yield at least a minimum sawlog of 8 feet long, measure and tally as a single stem. For each stem

above the fork estimate merchantable height and DBH (3-1/2 above point of severance.) Record each stem as a tree on the tally sheet.

2. If main stem yields less than an 8 foot sawlog, measure and tally as single stem provided the section will produce one or more 4 ft. pulpwood sticks. Estimate number of 4 ft. sticks available and record under PW. For each stem above the fork measure or estimate merchantable and DBH as in (1) depending on physical limitations.

h. During course of measuring trees mark each one with bright-colored keel to avoid duplication of tally.

Use of Form

Use Code as specified

Poletimber Trees (5.0 to 10.9 inches)

Tally DBH to nearest tenth inch; "cut" trees above and "leave" trees below the double line. Encircle cull trees. Do not tally sample poletimber trees in this space.

Sample Poletimber Trees (5.0 to 10.9 inches)

SP	-	Enter code number for species from column headings on Form
DBH	-	Nearest tenth inch - encircle culls
V	-	Vigor class, see code
C - L	-	Cut or leave, see code
HT	-	Merchantable height in feet to 4" DIB in multiples of 4 feet. Determine to top of last 4 ft. stick available.
% M	-	Percent merchantable

Witness Trees to Plot Center

SP	-	See code for species
DBH	-	Nearest inch
Bearing	-	To nearest degree
Links	-	To nearest tenth
Notes	-	Denote tree number in sample poletimber trees or sawtimber size trees.

Dead Trees

Consider merchantable pulpwood or sawlog trees which it is estimated died since 1947

SP	-	See code for species
DBH	-	Nearest tenth inch
CD	-	Cause of death; see code

Sawtimber Size Trees

SP	-	See code for species
DBH	-	To nearest tenth inch - encircle if cull for sawlogs
V	-	Vigor class; see code
C - L	-	Cut or leave; see code
Logs	-	Number 16 ft. logs to nearest half log. Cull approximately under %M if actual merchantable length is less than number logs recorded
U.S.	-	Number of 4 ft. pulpwood sticks in central stem above last saw cut for sawlogs
H. L.	-	Estimated number of 4 ft. pulpwood sticks in limbs of top
% M	-	Percent merchantable in sawlog portion of tree - to nearest 10% in tens
PW	-	Estimated number of pulpwood sticks in sawlog portion culled for sawlog. Denote position in tree; i.e., first, second log, etc. Example 1-8 means 8 sticks in first log.

Punching Data by 2" Classes

Disregard

Site Index Data

Choose 2 dominant or codominant trees, preferably the former, of either black cherry, white ash, red oaks, or yellow poplar.

SP	-	See code for species.
DBH	-	To nearest tenth inch
HT	-	Total height to nearest foot as measured by abney or comparable instrument
Age	-	Determine from increment boring

PRELIMINARY DRAFT

SOME RESULTS FROM REMEASURING PLOTS TO PLAN RESURVEY OF THE NORTHEAST

by

C. Allen Bickford

August, 1959

Northeastern Forest Experiment Station
Forest Service, U. S. Dept. of Agriculture

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I - INTRODUCTION

New Hampshire was the first state in the Northeast to be completed by forest survey. Thus the problems of resurvey in the Northeast first arose in relation to New Hampshire. Sampling for resurvey raises problems that were not important to initial survey. The theory for this sampling is still developing and standard texts are not as helpful as would be desired. A number of procedures are described and provide the initiated with a variety of useful methods. Their chief concern is with a sample from a fixed population or one that may be considered as an instantaneous sampling from a changing population. Let us look first at the problem of a forest manager as his problem is less complex than that of forest survey. He finds himself in the position of needing to know both what he has and how it is changing. Now it is possible to minimize cost at a fixed accuracy, or error at a fixed cost, with a single simple objective of the sampling. With two or more objectives, however, the simplicity disappears and the usual problem is insoluble. The forest manager may be in a fortunate position, however, if he can tolerate a greater error in growth than in current volume and if the ratio of corresponding variances does not exceed a value that may be computed.

The forest survey is also concerned with growth and with current volume and in addition must estimate timber cut and commercial forest area. Three years ago a design was proposed that would obtain these various statistics in a more efficient manner than had been used in forest survey up to that time. This proposal was based on partial information with respect to means, variances, correlations, etc. that would be decisive in determining whether or not the design proposed would really provide the needed data as efficiently as was claimed. The basic question was the relative sizes of error that could be accepted and the variances of the populations sampled. It was stated that accurate estimation of growth would require the least number of plots, that current volume would be intermediate, and that timber cut would require the most. Available experience had already shown that sampling which provided needed accuracy for current volume also met the requirements for area. If these relationships had been correctly assessed, remeasurement of a relatively small sample from initial survey would provide growth data and some information on current volume. An approximately equal number of new plots would give commercial forest area and current volume and a small additional number would be needed for timber cut. Thus a design was proposed that would provide needed statistics on area, volume, net growth, and timber cut in such a manner that prescribed standards of accuracy for all four elements would be met at, or near, least cost.

II. GOALS

The purpose of the proposed design has been stated. This paper is written to report some of the results of remeasuring a hundred plots in New Hampshire in 1956. These plots were remeasured to provide data that would help in designing resurvey throughout the northeast.

III. THE DESIGN CHOSEN AND WHY

1.--Design of initial survey.

The need for an efficient overall design has been pointed out. In order to understand why we chose a particular design it is necessary to understand the design of initial survey. If we are to reuse data from this initial survey, the manner in which trees and plots were selected must be recognized. Thus the design of initial survey will also affect resurvey design.

Initial survey design for New Hampshire and for all of the northeast was described in 1952.[1/] It amounts to a double sampling where large numbers of "photo plots" are classified to define strata of land in relation to land use and volume per acre on forest land. A subsample of these photo plots are examined on the ground to obtain volume means and variances by strata. This design differs from the triple sampling design[5/] used in Missouri, Florida, and elsewhere in the middle and late nineteen forties. The added stage classifies land as forested or not, thus the second stage of triple sampling defines forest strata as stand size class. These two stages were telescoped into one in the double sampling used in the northeast. Unpublished analyses made in cooperation with Chapman, have indicated that triple sampling was probably more efficient than double sampling where non-forest area was relatively large while the advantage shifted to double sampling when forest area was sufficiently increased. New Hampshire was 84% forested according to initial survey.[10/]

The efficiency of either design depends upon a large enough advantage to stratified sampling to offset the added complexity of field and office procedure and the costs of obtaining and preparing the aerial photographs as well as the actual photo interpretation. Thus availability of suitable aerial photographs is a requisite of either triple or double sampling as these procedures have been described in relation to forest survey. As we have been able to borrow photography, or at most buy prints, this cost has been very small in comparison with the savings from stratified sampling and the initial survey of the northeast has been completed under the double sampling design previously cited.

In using stratified sampling there is a choice in the manner of choosing samples within strata: they may be chosen proportional to strata weights or to strata variances. The former is usually called proportional sampling while the latter is called optimum (or Neyman) allocation. With a single simple objective and relatively large differences in variances by strata, optimum allocation is more efficient,[6/,9/] the ratio between standard deviations in different strata must equal or exceed two and the larger the ratio, the easier it is to benefit from optimum stratified sampling. There must be real differences between strata means for any form of stratified sampling to be advantageous. There must also be differences among strata variances to warrant use of optimum allocation by strata.

In initial survey, we also sought to obtain the most efficient distribution of effort between photo interpretation and ground plots.[a/]

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a/ Grosenbaugh described "plotless cruising" in 1952. This is a fast easy method of obtaining an estimate of current volume and other data. Following a test in east Texas, the Southern Station has adopted point sampling as standard procedure. We are not ready to adopt it in the northeast, however, for three reasons: so little of our field cost is incurred on the plot, the necessity of remeasuring sample areas to obtain full benefit from remeasurement, and uncertainty with respect to variances of net growth when points are reoccupied. Tests are underway to determine the extent we might gain from use of this method.

This required estimates of: cost per photo plot and per ground plot, proportion of forest land and of the various forest strata, and means and variances by strata. For the design we used, the mathematics of determining numbers of plots in the various categories is relatively simple. While our experience has been favorable, it is evident that the results can be no better than the estimates used in the calculations.

2.--Why plots are remeasured.

The advantages of remeasuring plots is commonly taken for granted even though the reasons may not be clearly understood. For the forest manager there are two good reasons: remeasured plots provide more efficient estimate of periodic growth and a means of updating results of a previous cruise. Both of these facets depend on the fact that there is correlation between successive observations of the same quantity on the same plot or other sampling unit. Thus we foresters ordinarily measure trees to estimate volume on a plot. If we measure and remeasure trees on the same plot, the resultant volumes are correlated. Furthermore, if this is done on a number of plots that are representative of a larger area such as a national forest, or a state, these successive measurements provide an unbiased basis for estimating periodic change and for adjusting data from the earlier measurement to the more recent one.

3.--Influence of the correlation coefficient.

Remeasured plots are an efficient means of estimating growth of a forest from the differences in plot volumes at successive measurements. This efficiency, which means that fewer plots are required to obtain the same accuracy, is a result of the correlation that has been noted. Growth could be estimated from two independent sets of plots in which case, the variance of growth is the sum of the variances of the two sets:

$s^2_{growth} = s^2_1 + s^2_2$, or if $s_1 = s_2$, $s^2_{growth} = 2s^2$ (s^2_i is the variance of i)

Now, if plots are remeasured, correlation affects the variance of the differences which is growth, as shown by:

$s^2_{growth} = s^2_1 + s^2_2 - 2\ rs_1s_2$ 8/ or, if $S_1 = S_2$, $S^2_{growth} = 2s^2(1-r)$ where

r is the correlation between 1 and 2.

Thus, when plots are remeasured, the variance of growth is reduced by $2rs_1s_2$, or by $2rs^2$, and it is evident that fewer remeasured plots would be needed for the same accuracy than would be the case with independent samples.

Remeasured plots are also useful for adjusting data from an earlier cruise to the present. It is evident the most recent data could be used in the same manner as the earlier data but without reference to them. This would be appropriate if all plots of the initial cruise were remeasured. Such a procedure is extravagant, however, unless needed for purposes of growth estimation. The efficient method is to remeasure some of the earlier plots and to use data from both sets of measurements. This is done by means of a regression equation, or a series of them, relating current volume to earlier volume. The sampling error of mean or total volume under this procedure is a function of the plot to plot variance of the latter remeasurements, the number of plots initially established, and $1 - r^2$. This is the same r as reduced the variance of growth as pointed out in the previous paragraph.

As this correlation affects both estimates of growth and of current inventory, it is appropriate to examine it more closely. What factors relating to forest sampling are likely to affect this correlation ? The strata used to obtain a more efficient sampling design might have an influence on both the regression and the correlation; this would be an indirect effect resulting from differences in density or age or some other unmeasured factor. Composition of the stand by species, e.g. forest type, might also affect regression and correlation. These are items for further study as the method is used and developed.

Another factor likely to be important is the time interval between successive measurements. In this case, it is reasonable to expect that r will diminish with time as a result of changes in volume on the plot due to trees that die, or are cut, and to the growth of other trees on the plot. We don't know how rapidly the correlations will decline, or how far they will go. This too should be carefully investigated as it is so important to any inventory scheme that makes use of remeasured plots.

4.--Principle alternatives in sampling successively.

Sampling the same population on successive occasions[9/, 11/] may be done in four ways that differ significantly in design: a series of independent samples; a fixed sample; a sub-sample; and a sample with partial replacement. A series of independent samples simply means that cruises are periodically repeated by taking a new sample on each occasion without regard to previous samples. This is what we do when we used temporary unmarked plots. A fixed sample means we use permanent plots and remeasure all of them. A sub-sample means to remeasure a sample of them at each occasion. A sample with partial replacement means that some of the plots of the first cruise are permanently marked and remeasured and some new plots are established subsequently.

The series of independent samples has been used frequently in forest inventory. If there is correlation between successive observations on the same plot, it is the least efficient of the four alternatives unless there are other differences in technique.[11/] The fixed sample is most efficient for measuring change while a subsample provides an efficient estimate of volume at a second occasion. When both current inventory and change are sought, as in forest survey, or by the manager of a national forest, etc., the best procedure depends on the allowable errors of growth and current volume and on the means,variances, and correlations that have been discussed. We don't know enough now to be specific for any particular situation but hope our experience will stimulate others to seek out the data required for their special circumstances.

5.--Why new plots, or why more plots were not remeasured.

In describing the overall design proposed for resurvey, the need for any new plots has been the most difficult point to explain. It is important that all who work at resurvey understand what is involved well enough to be able to explain to someone else. Experience to date clearly shows that this question will be asked and that it may be troublesome to answer convincingly.

The need for new plots arises from two facts: the decreasing amount of information that is obtained as additional plots are remeasured and the fact that for the likely periods between measurements, remeasurement of all of the initially established plots will result in a larger error than was obtained in the first place (where stratification has been used). Both of these facts are related to the correlation coefficient. Once enough plots have been remeasured to obtain an unbiased estimate of the correlation coefficient, r, there is no further advantage to remeasuring the old plots as we cannot reduce the variance of the

mean below $\frac{(1-r^2)\ \Sigma\ (Y - \bar{Y})^2}{n(n-1)(m-1)}$ with one independent variable where Y is an observed volume in 1956 $\bar{Y}$ is mean Y, n is number of initial ground plots and m is number of remeasured plots. The variance of Y, $S_y^2 = \frac{\Sigma(Y - \bar{Y})^2}{m - 1}$ is independent of the number of remeasured plots. Estimates of both r and S_y^2 depend on remeasured plots and once we have reliable estimates of them there is nothing to gain by remeasuring more of the old plots. New ground plots, on the other hand, reduce the sampling error of the mean indefinitely as $S_{\bar{x}} = S/\sqrt{N}$ and we can make the standard error of the mean as small as we wish, based on new plots, by merely increasing their number, N. Thus for efficient sampling to estimate current volume, some of the old plots should be remeasured and some new plots established.

6.--Strata to be used and their identification.

For purposes of initial survey, we have found that strata based on estimated gross volume in cubic feet has been an effective means of reducing the number of ground plots that were needed to meet accuracy goals. The first work in the northeast was aimed at recognition of stand size classes directly on the photographs. A test[2/] made on the Maryland eastern shore showed the superiority of using gross volume in cubic feet to define strata and the initial survey of the northeast was completed on this basis. As we shall continue to need estimates of current volume from newly established plots we expect to continue using these strata.

Additional bases of stratification are possible that might result in better estimates of the statistics reported by forest survey. Some that have been mentioned are: major forest type, site, timber cut, and silvicultural treatment. To be able to use these, or other criteria, for supplemental stratification it must be possible to use some scheme that uses aerial photos, previously prepared maps, or something of the sort so that ground plots are still a subsample of some higher sampling or classification procedures. Any of the above four have some promise that they may be recognized by use of aerial photographs but it is not necessary to limit additional strata to what may be seen on such photographs.

There are two principle alternatives in identifying strata: delineation of the whole area and classification of points or plots. Complete delineation means there is no sampling error to the proportions of area by strata, which is an advantage, but it is also considerably more expensive unless there is a large number of points per print. In such delineation, there is some minimum area that will be shown that will ordinarily be quite large in relation to the ground plot used to obtain an observation of volume per acre. Thus, on theoretical grounds, one might expect greater variation in observed volume under a delineation procedure than where smaller plots are classified.

Classifying points on aerial photographs is basic to the forest survey design for the northeast. They determine proportions by strata and the sampling error of these proportions. Experience on the Allegheny N.F. and elsewhere on the national forests of the Eastern Region, has been that variances by strata are no greater with delineation than with the point classification of forest survey. If the difference is small or negligible and the costs of delineation are not excessive, this is the method to use. It would be particularly helpful to a forest manager who needed to know where his stands were located as well as how much he had.

7.--The proposed design for resurvey in the northeast.

In this situation a design for resurvey was proposed at first informally around the station and subsequently as a talk to the Yale Forestry Club in March 1956, and in a paper at the survey techniques meeting, Sept. 1956[4/] in Kentucky. The main features of this design are as follows:

a. Remeasure enough plots to meet accuracy requirements with respect to growth . These same plots will also provide the basis for one or more regression equations to estimate current volume.

b. New photo interpretation of new aerial photographs to provide a more up to date stratification of the forest land. As proposed in 1956, a fixed sample of photo plots would have been used. This feature is not an essential element of the design and it now appears that independent samples may be more efficient for the successive series of aerial photographs because of the costs and errors involved in transferring photo plots from one set of photographs to another.

c. Establish enough new ground plots to meet accuracy requirements with respect to current inventory and timber cut.

IV - ONE HUNDRED PLOTS REMEASURED IN NEW HAMPSHIRE

1.--Introduction

Having selected a tentative design for resurvey of the northeast that would provide all statistics on area, current volume, growth, and timber cut in an efficient manner, the next problem was to make it more specific: How many plots to remeasure? How many photo plots to interpret? How many new plots to establish? Answers to these questions depended upon means, variances, and correlations that were unknown at that time. Using experience from remeasured plots in northwestern Penna., and elsewhere, it was estimated that we would meet accuracy requirements for growth by remeasuring 100 plots. The resultant data would then indicate needs as regards photo plots and new plots. Accordingly, one hundred

plots were selected from the plots of initial survey of New Hampshire as a proportional sample by county, major forest type, and photo interpreted stand size class. This selection was made early in 1956 and the remeasurements began early in July. Results obtained are reported below.

2.--Relocating plots.

A prime necessity for a scheme that relies on remeasured plots is that a substantial portion of them can be relocated at reasonable expense. When forest survey was initiated in the northeast in 1946 it was recognized that at least a portion of the plots might be remeasured. Field crews were accordingly asked to draw sketch maps to aid in subsequent plot relocation. This was a matter of continuing concern and field checks were made to find out how well these sketch maps were prepared. Until we set out to remeasure these plots in 1956 we had no substantial experience to guide us. At that time, ninety of the plots selected were actually found and remeasured and ten alternates[b] were used to obtain a hundred. Two different crews were used to remeasure these plots. Each had

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b. Actually, twelve alternates were reoccupied but two were not usable for one reason or another.

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had previous experience on initial survey in Maine and both reported that it took longer, on the average, to relocate old plots than to establish new plots.

3.--Reconciling the two tallies.

The field crews were provided copies of the initial tallies and instructed to tally dead trees and stumps as well as live trees. They were further instructed to compare the two tallies before leaving the plot to be certain there was no major disagreement in these tallies. These data were edited by a forester who had been on a field crew in Maine for initial survey to correct for differences that were too large. Even so some differences remained that were much too large to have resulted from the normal changes of a forest.

To reconcile these differences, the following conventions were adopted:

(1.) Remeasurement data were assumed correct where there was conflict.
(2.) Missed trees were presumed to have died and were included with mortality.
(3.) Maximum change during period is one two inch diameter class.
(4.) Merchantability class remains as made initially.

It is evident these conventions are likely to result in a biased estimate of net growth and that this estimate is more likely to be too small than it is to be too large. We hope to be able to avoid such assumptions in future data from remeasured plots.

This problem of obtaining agreement between successive tallies of trees on the same plot is extremely important to a design based on remeasured plots. This problem arises from errors of omission or duplication in either or both of the two tallies. It is further aggravated by mistakes with respect to the central tenth acre and by poletimber trees thereon which grew into sawtimber size during the period. It is evident these are problems that should be solved by the field crew on the plot rather than by editing data at headquarters. Field instructions have been amended as a result of this experience and data from plots remeasured in Hancock Co., Maine, late in 1958, were substantially better in this respect.

4.--Mean growth and its sampling error.

During the period between measurements of the same plot many changes occur to individual trees that affect net growth as reported by forest survey: Some trees die and the sum of their volume at death is periodic mortality for the plot. Some trees are cut and part or all of the wood is used commercially; the sum of these volumes is timber cut, of which more later. Some trees that were too small to have been tallied initially, grow enough in diameter to be included at remeasurement; the sum of their volumes when remeasured is ingrowth. Other trees live through the period in several categories: some previously sound develop defects that restrict their commercial use; some become so defective as to be unsuited for commercial use; and some trees with sound defects might become suitable for commercial use simply because of increased size. All trees that live through the period increase in diameter and most increase also in height. Volume added to sound merchantable trees that live through the period is called accretion. The increase in useless volume and the whole volume of trees that become useless is called cull increment. Volume added to trees that are cut or die between initial survey and cutting, or death, is included in net growth as defined for forest survey. Thus net growth reported by forest survey may be defined as ingrowth plus accretion plus changes in volume related to merchantability classifications plus volume added to trees that die or are cut minus mortality. It is evident that this is in effect volume when remeasured plus timber cut minus volume at initial measurement.

Periodic mortality for a plot is the sum of the volumes of trees that die during the period. Tree diameters were measured and volume estimated assuming average height of trees of the same species and diameter. Diameter was at least as great as when tallied in initial survey. From these data mean annual mortality in cubic feet was estimated as 8.2 cu. ft. per acre for the state as a whole. The corresponding sampling error was calculated to be 1.12 cu.ft. The coefficient of variation was 134 percent.

Net growth of each remeasured plot was obtained by use of the above definition as follows: volume as tallied in 1956 plus volume removed when cut minus initial volume. These estimates of growth are subject to possible bias, as discussed below, but are the best currently available. These data were analyzed to detect possibly useful strata for sampling growth, using the analysis of variance. Simple averages suggested that major forest type might have more effect than photo stand size or volume class. The first step then was analyses separately by white pine and northern hardwoods for these stand size classes. Calculated variance ratios were 1.25 ($F_{0.95} = 2.77$) for white pine and 1.755 ($F_{0.95} = 2.44$) for northern hardwoods. Thus the hypotheses of no differences in mean growth by "PI" class was accepted. There were too few remeasured plots in spruce-fir or aspen-birch to warrant analysis. The next test was with 98 plots testing major forest type, recognizing three. The computed F was 2.98 in comparison with $F_{0.95} = 3.09$ which does not reject the hypothesis of uniformity. Differences in mean annual growth per acre at 29.5, 8.9, and 20.8 are great enough, however, that we propose to accumulate more data rather than consider this test as final. Coefficients of variation were computed as follows:

	Coeff. of Variation	Mean annual net growth per acre in cu. ft.	S_i
white pine-hardwoods	71	29.5	20.8
spruce-fir	425	8.9	38.0
northern hardwoods	119	20.8	24.7
state (weighted average)	124	22	26.9

The spruce-fir entry is based on only fourteen plots.

There may be bias in the above estimates of net growth as 1947 estimates of merchantable height may be high in comparison with 1956 and because we were compelled to use average heights from inventory to estimate volume of cut trees. The editing that was done could also result in bias.

Thus for planning resurvey, we are not certain that we can stratify sampling to obtain required data on net growth. An average annual growth of 21.7 cu. ft. per acre per year means an allowable error in (percent)^2 of $(5^2 \times 10^9)/(4682200 \times 21.7295)$ which is equal to 245.72. Thus number of plots to remeasure is estimated from $n = c^2/e^2 = (123....)^2 / 245.72 = 62.48$ or 63 plots. Stratification by major forest type would reduce c to 118.78 and n to 57.4 plots where c is coefficient of variation and e is required accuracy in percent of the mean.

These data permit us to estimate the average annual net growth in cubic feet as 101,742,000 for the decade 1946-1956 for New Hampshire. The sampling error is 12,536,000 in comparison with 15,948,500 which is equivalent to 5% at 10^9 cu. ft. Thus our standard of accuracy has been met, so far as net growth is concerned, by remeasuring 100 plots.

5.--Timber cut.

Estimation of timber cut using data from the 100 remeasured plots is more straightforward than the estimation of net growth. The remeasurement crew recorded stumps on twenty two of the plots. Volume of timber cut for each stump was estimated using Hampf's charts[7] to obtain dbh and using corresponding average volume of live trees tallied in 1956. This treatment assumes[c] cut trees have the

c/ An analysis of trees cut and measured in our utilization studies is underway. This is expected to yield a stump volume table that will enable us to avoid this assumption.

the same average height as inventory trees and results in a probable underestimate of timber cut. Summing these estimated volumes gave us 22 observations with some cutting and 78 with none.

Treating the 100 plots as a simple random sample of the ten year cutting in New Hampshire results in a mean per acre of 206.6 cubic feet and a standard error of the mean of 57.1 cu. ft. Thus average annual timber cut for the period is estimated as 96,734,300 cu. ft. and a sampling error of 26,735,000; the corresponding standard of accuracy is only 15,575,000. Thus it is necessary to take more plots to achieve the desired accuracy in mean annual timber cut on the basis of a simple random sample. Timber cut could be estimated as a stratified sample with proportional allocation, using strata of initial inventory. This would reduce the sampling error to 25,470,000 which is still too large.

Assumed timber cut classes, such as were used in the Maryland test[2] were then tested and the resulting estimate of sampling error was 7,434,000 which is smaller than the above standard. With actual photo interpretation this error would be somewhat inflated as there would almost certainly be some errors in classification. It is at least possible that such strata might be enough to meet minimum requirements.

Means and variances in cu. ft. used in these calculations follow:

Strata	Mean cu. ft.	Standard deviation cu. ft.	Coefficient of variation percent
No apparent cut	6.8	35.3	520
Lightly cut	435	228	52
Heavily cut	1512	971	64
State as a whole (unstrat.)	206.6	571	276

There are two additional problems with regard to timber cut: an estimate is sought for a particular year and there is need for an estimate of amounts of timber products by classes. In an attempt to satisfy the first of these, the field crews were asked to record date of cutting using residual evidence on and near the plot and contacting nearby residents when available. No formal test was made but use of hardwood sprouts seemed to provide a reliable and objective basis if it could be assumed that these sprouts appeared promptly. Our sample was too small to obtain a reliable distribution by years. No attempt was made in 1956 to obtain data on timber products output or on logging and mill waste. Our emphasis was on remeasuring plots and procurement of these latter data requires a different approach.

6.--The regression equations used to estimate current volume.

Estimation of current volume under the design proposed for resurvey depends on three independent estimates: first and second estimates of current volume and estimated timber cut for the period. The first estimate of current volume uses one or more regressions derived from the data from remeasured plots. There were several questions to resolve about procedure for this estimate: What independent variables to use? How the dependent variable should be measured? How many equations would be necessary? Analysis from these remeasured plots has provided some tentative answers.

a. The dependent variable.

As the method was first proposed, the equation would estimate volume at the end of the period as though there had been no cutting. Current volume would then be obtained by deducting the estimated periodic timber cut. This procedure was chosen in the expectation that correlation would be so increased that a more efficient final estimate would result. The error of current volume so estimated would be the square root of the sum of the errors of timber cut and volume assuming no cut.

The alternative is to use volume as tallied in 1956 as the dependent variable. The error of this estimate would be obtained from a function of $S^2_{y.x}$ (or $S^2_{y12..}$) $= (1 - r^2$ (or $R^2)) S^2_y$. This method was used in adjusting data for four counties in northwestern Pennsylvania from 1947 to 1954. Its usefulness there could have been a special case and so both methods were tried using the New Hampshire data.

b. The independent variables.

Three independent variables were proposed initially: X_1 = volume at the beginning of the period, X_2 = length of the period in years, and X_3 = the sum of the squares of final dbh as estimated from sample tree data. X_2 was proposed in the expectation that data would become available which included considerable variation in X_2 and that intervals of various lengths would be well sampled. The New Hampshire data, however, included only two intervals: nine and ten years which did not provide much of a test for X_2.

X_3 was proposed on the basis of data from remeasured plots in Talmage Town, Maine[3]/ where a substantial advantage was indicated. Regressions based on sample trees were required to estimate 1956 d.b.h. from data of the initial survey. Only 130 sample trees were remeasured to provide equations for 16 species. Analysis led to three groups of species and these equations were used both to estimate X_3, at this point, and to estimate 1956 d.b.h. of trees cut during the period, see above. These equations said that 1956 dbh was equal to initial dbh plus ten year growth. For each, the hypothesis: slope of the line = 1, was tested and accepted. The coefficient for period length was not significant and one tenth of ten year growth was used as the best available approximation. It is evident the basis for New Hampshire was much weaker than for the Talmage data.

In addition to the foregoing quantitative variables we have the qualitative factors of major forest type and photo stand size class which might require identification to obtain a good estimate of 1956 volume. These problems were resolved by obtaining separate equations by major forest type, testing the hypotheses that coefficients were equal, and analyzing residuals for possibly significant differences by photo stand size classes. These analyses showed significant differences for major forest types but none for photo stand size class.

Further tests, using $F = \frac{(N - k)}{1 - R^2} (R^2_{Y123} - R_{y12})$ showed that in these data neither X_2 nor X_3 had a significant effect upon Y. Thus we came to the equations:

white pine; $Y_1 = 189.08 + 1.039X_1$; $r^2 = 0.8397$

spruce-fir; $Y_1 = 418.25 + 0.562X_1$; $r^2 = 0.4956$

north. hdwds; $Y_1 = 182.32 + 0.768X_1$; $r^2 = 0.7299$

where Y_1 was volume as tallied in 1956 plus the volume in cut trees adjusted to 1956, as described above. X_1 is volume at initial inventory as used to prepare state report cited above.

A parallel set of equations was obtained where the dependent variable was the volume tallied in 1956 with no adjustment. With these data, there was no analysis to determine if X_2 and X_3 should be included as the increased residual variance was bound to reduce the statistic for testing. The equations so obtained are:

white pine: $Y_2 = 289.96 + 0.643X_1$; $r^2 = 0.3860$

spruce-fir: $Y_2 = 746.54 + 0.237X_1$; $r^2 = 0.1002$

north. hdwds: $Y_2 = 275.27 + 0.525X_1$; $r^2 = 0.4776$

7.--Current volume and its sampling error.

The above sets of equations provided a basis for two estimates of current volume and its sampling error, using the stratification by photo stand size class of initial survey, and by major forest type as has been described.

One alternative is to estimate current volume assuming no cutting and then deduct estimated timber cut. This procedure results in a sampling error of 94,288,000 cubic feet. The accuracy standard is 88,650,000 (5,775,400 x 15.35) which says that we have not met our goal. This sampling error of current volume includes the error of timber cut that was previously reported but does not include contribution due to errors in classifying major forest type.

The other way, uses the second set of equations to adjust initial inventory for growth, mortality, cutting, and changes in definitions over the ten year period. In this case estimated sampling error is 77,435,000, which also neglects error of classifying forest type, and which is small enough to meet the accuracy standard. Thus direct estimation of current volume, without use of timber cut, is not only easier, it also has a smaller sampling error.

8.--Minimum numbers of plots required.

The foregoing analysis has shown that the hundred plots remeasured in 1956 in New Hampshire were sufficient to meet that standards of accuracy from the national manual for net growth and for current inventory but that our sampling error of timber cut is too large.

To illustrate the general procedure where two estimates are needed, lets look at the data reported for timber cut, assuming a simple random sample. As we have measured ten year timber cut, these data must be used. Let E be the allowable error as a proportion. E^2 was calculated as 0.025843... whence E = 0.16076... and the allowable error in mean timber cut per acre, E, is (0.16076...)(206.6) = 33.216...

$$\text{Now, } E_2^2 = \frac{S_1^2 E^2}{S_1^2 - E^2} = \frac{3262\ (33.216...)^2}{3362 - 1103.3...} = 1667.25...$$

$$\text{and the number of new plots is estimated by } n = \frac{(C.V.)^2}{E_2^2} = \frac{326200}{1667.25...} = 195.65...$$

which is the sample size of new plots that would be required for a simple random sample of timber cut. This, of course, is not the minimum number required to estimate timber cut as we expect to stratify forest area using two sets of aerial photographs. Using photo stand size classes as strata reduces n to 168 and these classes are not really efficient for estimating timber cut. The number of new plots required cannot be known until photo interpretation is done but it seems likely that less than 100 new plots would be needed.

9.--Numbers of plots recommended.

With the field work of the initial survey of the northeast completed last year, it was decided to do enough additional field work in New Hampshire during 1959 to provide data for a new state report. This meant that there would be need to remeasure some plots and to establish some new plots. The foregoing analysis had shown that minimum accuracy standards had been met for net growth and for current inventory with the 100 remeasured plots. This was due to a considerable degree to being able to use all plots of the initial survey, so far as current inventory is concerned. In another ten years, correlation might not be significant between current and initial volume and we would no longer be able to use all plots of initial survey. There was still need for some additional plots for purposes of timber cut. The problem was also influenced by plans to reinventory the White Mountain National Forest, using forest survey plots and design. Formula methods were not available but it seemed that the combination of remeasureing 25 plots from the 1956 sample, one hundred new plots, and one photo plot per print (about 3500 in all) would suffice for a new state report for New Hampshire. Work has been started to obtain the indicated data and we expect to prepare a new state report for New Hampshire as soon as data from the national forest are available.

V - SUMMARY

One hundred forest survey plots were remeasured in New Hampshire in 1956 to provide data that would be helpful in planning resurvey of the northeast. These data also provided useful experience with computational procedures that should increase the efficiency of resurvey. The principle results from field and office work have been:

1. No serious difficulties were found in this test of the resurvey design that was described at the Cumberland Falls survey techniques meeting in 1956.

2. It was possible to relocate ninety percent of the selected plots at reasonable expense. As these included some of the earliest plots to be established in the northeast, it is evident that plot relocation is not a serious obstacle to the design proposed.

3. The difficulties that were encountered in reconciling successive tallies have shown the need for careful and thorough work by the crew that makes the second tally. More recent plot remeasurements in Maine have produced much better results. There is still need for care but we know how to minimize the troubles that were encountered in New Hampshire.

4. Net growth showed no correlation with photo stand size class which was our only sound basis for stratification. Even as a simple random sample, one hundred plots were more than enough to satisfy accuracy standards. Stratification by major forest type showed promise of still further reducing the number of plots to remeasure; means and variances by these strata are reported.

5. If timber cut is treated as a simple random sample, the coefficient of variation, 276%, is so large that 100 plots are not enough to meet required accuracy. Stratification by photo stand size class was not much help. Classes based on amount of cutting showed considerable promise, however.

6. The best regression for adjusting initial volume to 1956 was the simplest: volume as retallied over initial volume by 1947 standards. Neither length of period nor estimated 1956 basal area had a significant effect. Three major forest types were used where correlations were 0.31, 0.62, and 0.69 for spruce-fir, white pine, and northern hardwoods respectively. Use of these regressions resulted in an estimate of current volume that met required accuracy without any new plots (neglecting any contribution to error due to proportions by major forest type).

7. A computational procedure has been worked out that was adequate for this preliminary report but that will require strengthening for actual use in resurvey. New photographs have been interpreted to obtain stratification by major forest type and by amount of cutting (timber cut class).

Thus our objective has been met and we have begun resurvey of the northeast. We expect further refinement in detail but the general outlines remain: double sampling based on successive sets of aerial photographs; stratified sampling by volume class, major forest type, and timber cut class; remeasurement of some plots, establishment of some new plots, with numbers of plots in the various categories calculated to meet the several standards of accuracy for area, growth, current volume, and timber cut. Our experience in New Hampshire has served us well.

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RE-NE
FOREST SURVEY
General
(Eastern Techniques Meeting) September 1956

TOPIC 21-PROPOSED DESIGN FOR CONTINUOUS INVENTORY: A SYSTEM OF PERPETUAL FOREST SURVEY FOR THE NORTHEAST

by

C. Allen Bickford

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1. INTRODUCTION

The forest survey was undertaken to determine the amount of our timber resource and how it was changing. At first it was only a timber cruise on a grand scale. The realization has come gradually that growth and timber cut are as important as inventory area and volume. There has also come recognition of the need for various supplementary information such as condition of the forest in relation to the kind of owner. At first, all that seemed necessary was a once over cruise. The importance of a continuing job has emerged and with it a need has arisen for a comprehensive overall approach with a coordinated design that would provide all or most of the required data.

The method that is described below has been planned to provide nearly all the required data under a single sampling design. In the northeast, we are nearing the end of our initial inventory and the problem of resurvey is upon us. This proposal, which we call perpetual forest survey, is a design for resurvey that we expect will enable us to move toward maximum efficiency as rapidly as we know the essential basic parameters: Means, variances, and costs.

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Under this method, we would be measuring and remeasuring approximately equal numbers of plots every year. These plots would be scattered throughout the northeast from Madawaska and Calais in Maine to the Big Sandy River that separates West Virginia from Kentucky. Every year some plots would be measured in almost every county of the twelve states. The data so obtained would enable us to report on the status of the forest resource for the northeast, or any part of it, on relatively short notice. The next national review or reappraisal might be done almost entirely with our punched card machines. Our field crews would have stable headquarters. And we expect to reduce cost at the same time.

II. THE PROPOSED METHOD

A. The Method in Brief.

This method was conceived as a coordinated and efficient means of obtaining the required data for Forest Survey on a perpetual basis. Three aspects are involved: an overall design, an equalization of the annual job throughout our region, and an organizational set up to get it done. It is sketched briefly in the following paragraphs so that you may see how the parts fit together. Then I shall describe the parts in detail.

First, let's sketch the overall design. Take a look at figure 1 and you will see a sketch of our proposed sampling procedure. This is a form of double sampling. A large number of photo plots are classified as to land use and the forested plots are classified as to cubic foot volume class. A sample of these plots also serve as ground plots on which trees are measured and the stand is classified.

In the initial survey a large number, H, of photo plots was used. A portion of them, h, was used as ground plots. In the resurvey, another subsample, N, which includes the h ground plots of initial survey, will serve as a permanent sample of photo plots. In figure 1, N is obtained by adding the h ground plots of initial survey to the (N-h) photo plots under RESURVEY I. The remainder, (H-N) is not used after the initial survey.

Resurvey would recognize two kinds of ground plots: remeasured and new. In figure 1, remeasured plots are identified by green lines, new ground plots by brown, and remainders by red. You will observe that in RESURVEY I, all the remeasured plots (m_1) come from the h ground plots of initial survey while all the new ground plots (n_1) come from the (N-h) photo plots of resurvey that were not ground plots in the initial survey. There after, remeasured plots come from both previously remeasured and former new ground plots while new ground plots come from those that were not ground plots at the previous round.

Specific numbers of plots are obtained by calculating estimated numbers required to meet accuracy standards of forest survey from the best available information. Number of remeasured plots are determined expecting to satisfy accuracy standards of net growth. We hope this number will also be large enough for an accurate determination of the needed regressions and to obtain data required by ownership class. Numbers of new inventory plots (both photo and ground) will be calculated to meet accuracy standards of inventory volume when used with the adjusted initial volume. Numbers of plots for measuring stumps are

determined by accuracy standards of timber cut. Stumps will be measured and trees tallied on all plots and the data used as fully as possible in estimating the three quantities: inventory, growth and cut.

We seek estimates of five quantities: commercial forest area, volume, growth and mortality, timber cut, and product output. In figure 2, the estimation of these data is sketched. Required area data are estimated from gross area (A), resurvey photo plots (N), remeasured ground plots (m), and new ground plots (n), obtaining commercial forest area (F), area by major forest type (F_i), and area by timber cut class (C_i) as intermediate steps.

Volume data are estimated in two stages: first two independent estimates are made of volume and then their weighted average is estimated total net volume as required for tables 4, 5, 6, 7, and 8. The first estimate is obtained from gross area (A), initial photo plots (H), initial ground plots (h), and remeasured ground plots (m). The second estimate is obtained from gross area (A), resurvey photo plots (N), and new ground plots (n). Notice that these two estimates are independent of each other.

Growth and mortality data are estimated from the remeasured plots (m) and the area data obtained above. Remeasured plots provide the most efficient basis for estimating mean growth and mean mortality by major forest type (F_i).

Timber cut data are obtained from areas by timber cut classes and from the remeasured and new ground plots. Mean timber cut by classes is converted into total timber cut in the detail required by the national manual.

Product output data is the only item not obtained from the general design. Instead, this must come from supplementary information from Bureau of Census, state forester or other office, or by special study as circumstances dictate.

The annual job throughout our region is equalized by estimating required numbers of plots of the various kinds and distributing them as equally as we can through the period. We don't know now just how many plots might be necessary. Suppose N should be 40,000, m=2000, and n=2000 for the 12 states in our territory. At ten years between measurements, we would need N = 4,000, m = 200, and n = 200 each year. These plots would be distributed by state, county, major forest type, and cubic foot volume class in proportion to the distribution of commercial forest area as nearly as possible.

The final aspect of the proposed method is an organization to obtain and process the data. For this we would do the field work through our research centers with training, guidance, etc. from Upper Darby headquarters as necessary. Data compilation and analysis would continue to be done at Upper Darby as we do now. The set up is outlined in figure 3; we will come back to these charts as we go into the more detailed description.

B. Data Required and Where Obtained

1. Area by Various Classes.

Area data required include: area by classes of land use, commercial forest area by ownership and stand-size class, and commercial forest area by major forest types, as specified in national Forest Survey Manual, 1952 edition. In addition, we propose to use area of commercial forest land by major forest type and photo volume (or stand-size) class in our sampling design. These data would be obtained from total land area and interpretation of most recent available photographs, adjusting on the basis of classification of ground plots.

2. Inventory Volume by Required Sorts.

Total volume in cubic feet and board feet sorted by stand size class, ownership class, species, diameter, and class of material are required inventory volume data. Total inventory volume at a given time would be the weighted average of two independent estimates: the first estimate is initial volume adjusted by regression based on remeasured plots and the second estimate is derived from a fresh sample. Sorting these data, as required is more complex and is described below.

3. Net Growth.

Net annual growth in cubic feet and board feet by species group and tree size class is required. Periodic net growth would be obtained from remeasured plots as an average per acre by major forest type and converted to a total per year. Totalling these data would provide net annual growth for a date. Sorting by tree species and size group would be done from the plot data.

4. Timber Cut and Output of Products.

Timber cut in sawtimber and growing stock sorted by species and tree size is a required item. These data would be estimated, using cutting strata identified from aerial photographs, and from stump measurements on plots.

Timber products cut from growing stock and other sources, sorted by species group and product are also required. Estimates of these volumes would rely on Census data and similar sources, where available, supplemented by special studies when there is need.

5. Other Data.

a. Productivity class or cutting practice level might be desired when another national review or appraisal is made. Classification of ground plots could provide such data.

b. Growth and growing stock projections are needed to estimate "Timber growth and volume outlook". Foregoing data on inventory, growth, and timber cut are adequate for these estimates.

c. Current and prospective stocking, or something of the sort may be desired, or still other data. When such needs arise, it will become necessary to show how the data may be obtained.

C. The General Design Proposed for the Northeast

1. Choice of Sampling Design.

There are many sampling designs which might be used to provide estimates of the required data. Before recommending the design proposed, some alternatives were considered and compared. These included: a series of independent samples, a fixed sample, and sampling with partial replacement. There were also some variations in detail within these three broad types. The method described below was chosen as it was better than the alternatives considered in the comparisons that were made.

The design proposed (see figure 1) is a fixed sample of photo plots supplemented by a partly fixed sample of remeasured ground plots, and by new ground plots not scheduled for remeasurement. All ground plots are drawn from the fixed sample of photo plots. Some replacement of remeasured ground plots will be necessary because of losses to non forest uses: roads, housing developments, etc. Partial replacement may be a superior sampling technique, besides.

Within this general framework there are at least two alternatives that would provide the required data and which vary materially in sampling design. The method proposed here presumes complete photo coverage will be available about every ten years at a scale of about 1:15000. The other alternative will be described by Hasel and is based on partial coverage in strips at a scale of about 1:5000; this coverage too would be repeated about every ten years.

2. New Photographs

We assume new photographs will become available about every ten years. It may be desirable to vary this interval in relation to rate of change in area classification due to growth and cutting and with reference to the rate of stump deterioration from insects and decay. Length of desired interval should be capable or fairly precise definition on the basis of related facts.

You are probably more concerned by the lack of any reasonably complete coverage that is new enough to define usable strata. We have that problem in Maine. The indications are that without aerial photographs, we are compelled to choose between prohibitive costs and an excessive sampling error. When we discussed the matter in Washington last April, it was agreed we should try to beg or borrow new photographs as needed and if that should fail, the Forest Survey should purchase them. In any event, this proposal and Hasel's that follows assume we will have the needed photographs.

3. Photo Plots Provide the Basic Framework

A sample of plots will be drawn from photo plots 1/ of the initial survey to provide a permanent sampling structure for resurvey.

1/ We expect this number to be larger than the number needed for resurvey, but if the reverse should be true, we would simple add the necessary number of photo plots.

As new photographs become available these plots are to be transcribed as accurately as we can at reasonable cost. Numbers of these plots required to meet accuracy standards for inventory volume and timber cut will be computed, using formula 2 of figure 4. Whichever number is larger will be used an N, see figure 1, and this number of plots would be selected in a random fashion from the photo plots of the initial survey.

4. Remeasured Plots, How Many, and How Selected.

Number of ground plots, m, needed to obtain desired accuracy in estimated net growth will be determined using formula 3 in figure 4. Estimates of numbers required will be made for each major forest type within a state, since major forest type is our first step in stratification. Where the area of such a type is small, it should be combined with the same type in an adjoining state for some of the calculations at least.

This number would then be distributed by counties and photo volume (or stand-size) class, using proportional allocation based on commercial forest area of the major forest type. Original field plots will be sorted into these classes and the calculated number of plots drawn from them in a random manner. This step is illustrated below with New Hampshire data. Should the calculated number be greater than original number, remeasure all and draw a random sample from the new plots to provide the proper number during the next period.

Selection of plots for remeasurement should also show their distribution by years during the ten year cycle between summaries (see table 5). As this proposed method is new, it is obvious there will be a transition period during which the ideal is approximated as well as other factors permit. Furthermore, in scheduling remeasurements, we do not want a fixed interval between measurements. Summary of the data will require adjusting data for varying periods of time and our remeasured plots should cover the expected range.

5. New Plots, How Many, and How Selected.

The next problem is to estimate how many new plots are needed to obtain current inventory volume with desired accuracy. Current inventory volume, as pointed out above (section B 2), is the weighted average of the first and second estimates. Thus the sampling error of current volume is a function of the sampling errors of these estimates (formula 4, figure 4).

The sampling error of the first estimate (formula 6) depends on pertinent variances and the following numbers of plots: initial photo (H), initial ground (h), and remeasured ground (m). When these numbers of plots are known, the sampling error of the first estimate can be calculated. Thus, when the desired accuracy of current inventory volume is also specified, the needed accuracy of the second estimate can be calculated (formula 5). And corresponding numbers of plots (N and n) can be obtained (formulae 1 and 2). Numbers of new ground plots by photo volume class would be distributed using optimum allocation (formula 8) as in initial inventory. Numbers of plots so calculated are subject to revision to meet the needs of timber cut as explained below.

6. Cut Plots, How Many, and How Selected.

Timber cut is a different population and uses different strata, but as the mathematics is the same, formulae 1, 2, and 8 are also used to estimate numbers of photo and ground plots and to distribute them by timber cut strata. Computational procedure is indicated by table 3. As the same plots are photo interpreted for both timber cut and cubic foot volume class, the top part of the table is calculated from numbers of photo plots by the classes shown.

Distribution of ground plots is more complex. Total number of these plots in a volume stratum is given by the optimum allocation formula. And the same formula, with different values, estimates total number for each timber cut stratum. These numbers are then distributed within a volume, or timber cut, stratum using proportional allocation. Two sets of numbers could be computed for each of the 32 cells (8 volume classes by 4 timber cut classes) containing some forest area and the larger number would be used in the ground survey. Actually where there is little or no cutting, numbers for inventory would always be larger whereas with heavy cutting, numbers for timber cut would be larger. Where there is doubt, compute both numbers and use the larger.

7. The Photo Interpretation Job.

As new photography becomes available, the old photo plots will be located on it and interpreted as to major forest type, volume class, and timber cut class. Forest type will be determined from relative amounts of softwoods and hardwoods, topographic location of the stand, general acquaintance with the area, and knowing where the picture was taken. Volume class will be determined by present methods and with improved techniques as they are developed. Timber cut class will be determined from apparent cutting on most recent photographs using older photographs and any other aids that may be developed.

8. The Field Job.

The field job consists of finding the selected plots and procuring certain data on each of them. New plots are to be located with care and marked to make relocation easier. Ground plots of the initial inventory have been established from the beginning in 1946, with remeasurement in mind. Since about 1950 improved mapping and marking procedures have been used that should make it relatively easy to find nearly all of the plots. Bark scribes have been used to mark the route to the plot and live trees on the plot. Sample trees have been tallied in order clockwise from north azimuth. And dead trees have been blazed in a distinctive fashion. Thus, we can reidentify individual sample trees and separate net change on each remeasured plot into: mortality, timber cut, ingrowth, and accretion.

Data needed for a plot include: Current net volume (including net volume of sound and rotten cull and salvable dead volume) by species, size, and quality; timber cut during the specified perird, net growth since last measurement (including mortality by cause); ownership by the classes listed in the manual; and perhaps the amount of logging residues where there has been cutting. To obtain these data, on new plots trees will be tallied by species and diameter etc., as in our present survey, and stumps will be measured in height and diameter and species determined. Date of cutting will be determined from hardwood sprouts and other clues on or near the plot. And the plot will be classified with respect to stand size and forest type (S.A.F.) from the stand in which it lies.

For remeasured plots, all these data will also be taken and in addition, the sample trees will be reidentified, new dead trees and in-growth will be identified and tallied by species and dbh and ownership class will be determined. Sample trees will be reidentified by position, size, and species. New dead trees will be those dead without the characteristic blaze. Some may be missed where there has been cutting that removed dead trees. Ingrowth trees will be those of merchantable size but without a bark scribe.

Ownership class if more difficult. The plot must be located with reference to property lines of a metes and bounds survey and ownership determined from local inquiry verified by records in a county office. It will not be easy but there seems to be no reasonable alternative: area by ownership class is required and to do this there must be either a probability sample or a complete enumeration of all classes but one.

In either case, the owner must be identified to be able to classify land by classes of owner. Remeasured plots alone may be inadequate for our purpose. If so, additional sampling will be necessary. The first time over is certain to consume many frustrating man months of searching. But, once the job has been done, it should be easier to run down changes.

9. Estimating the Data Required.

Now let's see how these data would be put together to obtain the information called for in the manual. The general procedure was outlined in figure 2 and now we shall go into details. At any given time, our data would consist of: a number of photo plots classified as to major forest type, cubic foot volume class, and recent cutting; a sample of these plots drawn from all strata, about half new and half remeasured, where trees and stumps have been tallied. Photo interpretation, and thus stratification, might be based on photographs as much as ten years old. Furthermore, the ground plots would have been measured over a ten year period - some in every year. And we should expect to have had cutting that affected these plots in every one of the ten years. We shall now show how the data for the national Standard Tables 1 to 10 may be obtained from such information.

a. Commercial Forest Area

Area data required are those for tables 1, 2, and 3. These areas would be estimated from total areas by counties, numbers of photo plots by major forest type and volume class, and numbers of ground plots by stand-size class, S.A.F. type, and ownership class. The first step would be to prepare table 1, for each county, or group of adjoining counties (see table 1). This table shows numbers of plots, proportions, and areas by volume class and major forest type. It is recognized that the basis for these data may be as much as ten years old but changes in area by type should be small and volume class is primarily an aid in sampling. State summaries are obtained by combining these county data. Area data for national Standard Table 1 would be obtained as follows: area of class 9 is unreserved nonproductive; area of class 0 is non forest; reserved area is obtained independently and productive portion is deducted from the total area in classes 1 through 8 to give commercial forest land as the remainder. Total areas by major forest type would be the areas entered in national Standard Table 3.

Next, table 2 would be prepared for each major forest type of a state. Numbers of photo plots and proportions by photo volume strata would be copied from table 1, for the state. Numbers of ground plots would be obtained by sorting by stand-size class within a photo volume stratum and counting. Proportions would be computed, as shown for the table, and then summed by stand-size class. These summed proportions, multiplied by total area of the major forest type, would provide estimates of area by stand size class for the type. Summing these areas by

stand-size class over all types would give area by stand-size class for the state, and these are the data needed for national Standard Table 2 for the line of all ownerships.

There will have been changes due to growth, cutting, fire, wind, etc., for which no adjustment has been made. These factors tend to compensate to some degree, however, and errors are expected to be small enough that they may be ignored with impunity. We plan to determine how large these errors are, however, to be sure we can neglect them. In the event of another 1938 hurricane, or something of the sort, a special survey would be required to adjust area by classes.

The final item under commercial forest area is distribution by ownership class. This would be done using ownership classifications of the remeasured plots and appropriate expansion factors. Each plot would have a corresponding area, thus sorting by stand-size and ownership class and summing would provide the data needed for national Standard Table 2.

b. <u>Inventory Volume</u>

As pointed out above, total inventory volume for a given year will be the weighted average of two independent estimates. The first is obtained from the data of the initial inventory adjusted to the year desired using regression based on remeasured plots. The second is obtained from photo interpretation of new photographs and on new ground plots, adjusted to the year desired. Weighting is based on the reciprocals of variance formula 9, figure 4.

(1) First Estimate

The first estimate is obtained by adjusting initial inventory volume to the desired year and deducting periodic timber cut. Adjustment would be accomplished using the following regression equation based on remeasured plots.

$$Y = a + b_1 X_1 - b_2 X_2 + b_3 X_3$$

The dependent variable, Y, is measured volume at the end of the period. On plots where there had been cutting during the period, Y, would include estimated volume at end of period of these cut trees. There would be no corresponding adjustment for trees that died, however. For these cut trees, dbh when cut would be estimated from stump measurements and adjusted to end of period using regression based on remeasured sample trees (see below).

X_1 is measured volume at the beginning of the period. It is simply the sum of the volumes of the trees tallied at that time.

X_2 is length of period in years. It is determined by number of growing seasons between measurements. At first we shall assume July 1st as the date to use in counting growing seasons, subject to revision, locally if desirable, when we know more precisely how dbh growth is distributed during the year. Future measurements, including those of 1956, will be confined to the dormant season.

X_3 is volume at end of period estimated from sample tree data. It will depend on regressions based on remeasured sample trees. Separate regressions will be obtained by species and vigor class. Each would be of the form $Y = a + b_1 X_1 + b_2 X_2$. The dependent variable is dbh when last measured. Independent variables are dbh when first measured and length of period in years as for X_2 above. For each remeasured plot volume at end of period is estimated as the sum of the estimated volumes or basal areas of all trees tallied at the beginning. Basal area would be easier to estimate and might be as well correlated for purposes of plot regression. This estimate neglects cutting, mortality, and ingrowth.

Separate regression equations, based on remeasured plots, will be obtained for each major forest type, probably combining data from adjoining states. These equations will be used to estimate means, for the strata defined by initial photo interpretation at the desired date in the absence of cutting. Then the sum of $P_i\bar{Y}_i$ is a weighted average volume at that date. Multiplying it by an appropriate factor gives an estimate of total volume if there had been no cutting. Provision for mortality and ingrowth would be implicit in the regression based on remeasured plots. Subtracting estimated periodic timber cut (see below) provides our <u>first estimate</u> of total volume. There may be need to adjust for timber cut during two periods: establishment to most recent photographs and then to desired date. An approximately parallel procedure would provide data required to estimate the associated sampling error (see formula 6 fig. 4).

(2) Second Estimate.

The second estimate, and its sampling error, will be obtained from new photographs and new plots in a very similar fashion to the method we have used in initial inventory. Our new ground plots will have been measured over several years that will often differ from the desired date. Observed volumes will be adjusted accordingly, using the regression based on remeasured plots used in obtaining the first estimate. A correction for timber cut will also be needed here for area represented by plots measured a year or more before the desired date. The method is described above.

(3) Volume by Stand-Size Class and Other Required Sorts.

The method of obtaining total volume has been described. The next problem is to distribute this volume by stand-size class, ownership, species, etc., as needed for the national Standard Tables. One way of going about it would be to compute the variances for each of the required details in the 2 estimates and combine them by weighting as with total volume. This is unnecessarily laborious in view of the relatively large sampling errors and the fact that an easier approximate method can be used. Under this method, an appropriate factor is calculated for use with ground plot, both remeasured and new. Two sets of factors are needed.

Remeasured plots: $$W_{1i} = \frac{s^2_{\bar{y}2} A_{1i}}{m_{1i} a_1 (s^2_{\bar{y}_1} + s^2_{\bar{y}2})}$$

New plots: $$W_{2i} = \frac{s^2_{\bar{y}} A_{2i}}{n_{1i} a_2 (s^2_{\bar{y}1} + s^2_{\bar{y}2})}$$

Use of these factors enables us to estimate the data needed for national Standard Tables 4, 5, 6, 7 and 8 although some small final adjustment may be needed to achieve agreement with total inventory volume as estimated above.

c. Net Growth.

Net growth is required for national Standard Table 9, as well as annual mortality by cause of death, in board feet and cubic feet by species groups and by tree size. For each remeasured plot we expect to obtain net growth for the period between measurements and its distribution by mortality, ingrowth, and accretion, and timber cut. Analysis of remeasured forest survey plots in Pennsylvania and of other remeasured plots in New Hampshire and Maine has failed to reveal any significant correlation of net growth with growing stock. It is likely, however, that net growth will vary with forest type and by site class within such a type. Our proposed design will provide for the determination of average net growth by major forest type to the precision required. Should subsequent analysis reveal significant correlation or usable strata, the sampling error would be reduced accordingly.

Our planned procedure calls for the determination of net periodic growth for each remeasured plot, conversion to net annual growth, estimation of mean net annual growth by major forest type, expansion to total net annual growth for the type, and summing over all types to obtain the state totals needed for standard table 9.

Net growth for a plot where there has been no cutting, is merely the difference in net volume over the period. With cutting, net growth becomes end volume plus timber cut minus volume at the beginning thus it is only necessary to add the volume corresponding to the measured stumps to obtain net growth of plots where there has been cutting, see figure 5. Growth on cut trees prior to cutting is included.

Mortality is the volume of trees that die. Its estimation would be made in the same manner as net growth from plot to major forest type to state total.

Ingrowth is not required but we make an estimate of it because it is locally important. It would be compiled in the same manner as mortality.

d. Timber Cut.

Volume of timber cut and volume of resulting products are the data required for national Standard Tables 9 and 10. It is further necessary to sort timber cut by product and species group and to report these data in cubic feet and board feet. Volume of products cut is needed by principal products in various units.

Our proposed design would obtain total periodic timber cut, using the method described by Bickford, Chapman, and Caporaso. This amounts to defining strata from aerial photographs, obtaining strata means and standard deviations from ground plots, and expanding to total volume as we now do in initial survey.

For each plot, remeasured or new, an estimate of timber cut is obtained from measured stumps which provides the necessary detail to obtain volume in cubic feet and board feet by hardwoods and softwoods. These plot data are then used to estimate strata means and standard deviations.

Estimating timber cut from stump data would also permit us to distribute this volume by classes of estimated dbh. When remeasured plots are cut, we would also be able to obtain the distribution by quality classes as of the last measurement before cutting. Knowing the date when each plot was cut provides a basis for distributing timber cut by years within the period.

Volume of timber products cut by the required products would have to be obtained separately. We suggest using the periodic census of lumber manufactured as a base, obtaining comparable data for other products for the same year, converting to timber cut, and assuming the same proportions by products apply throughout the period. Local data available through the state forester's office, or elsewhere should be used when available and reliable.

Distribution of timber cut between products and logging waste would be based on local utilization studies. Basic calculations would be in cubic feet with conversions to board feet.

Total timber cut estimated from photostrata and measured stumps would not be affected by these distributions to products and logging waste.

e. Other Data.

The need for additional data by ownership class has led some to ask if we could obtain data on volume, growth, productivity class, etc., by ownership class. We can if ownership is classified for a probability sample of plots which enable us to estimate the desired quantities. Under this proposal we would know ownership only for the remeasured plots. As these would be drawn by proportional sampling we could estimate whatever we also measure or classify on these plots.

If it should be desired to estimate productivity class, or something of the sort, for recently cut areas, it is only necessary to define terms and classify the plots that fall in such areas.

Growth and Growing Stock Projections call for data not specifically included above. It should be evident, however, that such data could be estimated without going into detailed procedure here.

D. Organization, Personnel, and Responsibilities.

The foregoing proposal for putting the resurvey job on an annual basis all over the Northeast could be done in several ways. The present general type of forest Survey organization, headquartered at Upper Darby could do it.

It is evident such an arrangement would require considerable travelling on the part of field crews. It is also clear that there would be the liklihood of excessive lost time from inclement weather which might not be easy to put to productive use. To avoid these and related problems, it is proposed that the field job of the Forest Survey be done through the various research centers (see figure 3). They would be strengthened, of course, to be able to do this job in addition to their present duties.

Supervision, inspection and training would be provided by the Director's staff, as is now the case in other divisions. Photo interpretation, compilation, and analysis would continue to be the responsibility of personnel at Upper Darby. Report writing should be a joint responsibility to give all involved a share of the writing experience and the training and credit that goes with it.

Photo interpretation would become the function of a specialist who knew the techniques of photogrammetry and who was reasonably familiar with local stand conditions throughout the northeast. It would be his responsibility to photo interpret new pictures as they became available, prepare pictures for field use and train field crews in the use of aerial photographs as there may be need.

Overall coordination would be provided by the Forest Survey leader, headquartered at Upper Darby. It would be his responsibility to determine numbers of plots and their distribution by years between the centers. He would also provide the necessary training and inspection and arrange for cooperation with interested parties.

It would be the responsibility of the center leader to fit this job into his program, both as regards personnel and timing. He would name one or more of his professionally trained foresters as party chief and provide him with a second man as helper. This second man could be a summer student, a year long subprofessional, or a short term temporary employee as conditions indicate. Ordinarily the best time for measuring these plots would be before or after the period of most active growth (May to August). In much of our territory, this would mean the late summer and fall which is a very pleasant time to be in the woods.

E. Related Matters.

The forest survey is related to a number of other activities and interests. I have attempted here to sketch the expected impact of this proposal on some of them and how they might affect the proposal.

1. Future improvement in techniques of forest survey should tend to increase the efficiency of the operation. You may wonder if this proposal which attempts to use a single overall design would lend itself to the necessary modification. Let me begin by admitting that it is unlikely that this proposal as now conceived could be modified to cover all possible cases.

But there are a number of situations which could be met. For example, should improved methods of photogrammetry result in perhaps more usable strata and less variation within strata or, if we can improve our means of getting on plots so that we average 4 plots per crew day instead of 2, or other similar improvements, it is clear we could adjust numbers of plots using other means, variances, and costs without difficulty.

2. The proposed design if flexible in that many changes in detail can be permitted without upsetting the overall coordination and efficiency. As pointed out above we can accommodate changes in means, variances, and costs. It is also possible to vary the schedule in time, concentrate temporarily in one area, intensify the sampling locally, add special information, etc., without weakening the basis for the important required data.

3. Variations in financing are then less upsetting as we could obtain more data or push up the schedule when on a crest or vice versa when short handed and still expect to satisfy the overall objectives of the forest survey.

4. The station's efforts would be better coordinated if men at the research centers were helping more actively in obtaining data. They would be better able to discuss and defend our procedures and we should expect them to develop some good ideas for further improvement.

5. The morale of the survey crews would be improved as they would have a greater sense of belonging to the whole station, as they worked closer with men in other fields, and from the liklihood of longer residence at one place.

6. Warning service with respect to forest pests could be set up in connection with this annual ground plot work all over the northeast by training the men in what to look for, etc.

7. Future timber resource reviews would be made easier as a large part of the data could be taken on these ground plots and much special information could be obtained quickly using the proposed sampling structure.

8. Cooperation has meant much to us in the past especially in obtaining statewide photo coverage of some of our states. Would they be as interested in providing photographs for this design? Possibly not, but on the other hand other factors might increase their interest, or that of others. There is considerable local interest now in growth based on remeasured plots. Industry in Maine has established about 1200 such plots and 200 or so have been remeasured. The Allegheny National Forest is currently using a local intensification of the survey to obtain data they need for timber management. If we could interest enough others in measuring our plots, that cooperation should make it easier to buy aerial photographs if that should become an obstacle.

III. HOW IT MIGHT WORK IN NEW HAMPSHIRE

A. Introduction

The initial survey of New Hampshire was done in 1946, 1947, and 1948 and while several plots have been revisited for special purposes, no plots had been completely remeasured until this past July. Thus, it is evident we cannot immediately use the balanced form of a perpetual method of survey. Rather, the first remeasurement should be done over a relatively short period and then stretch out the next remeasurement to more nearly approximate perpetual forest survey.

We began in New Hampshire, using a hodge-podge of photography from several sources with a system that had not been completely worked out. Numbers of plots at 15,189 photo plots and 912 ground plots are high in comparison with more recent practice. Some field plots are half acres and others are fifth acres, etc. The 912 ground plots are a sub-sample of the 15,189 photo plots using optimum allocation by stand-size class (photo) Bickford, 1952, has described the procedure in detail. From these data we have estimates of commercial forest area by major forest type for the state, as shown in table 1, and for each county in the state.

B. Numbers of Plots.

1. How Many Remeasured Plots to Estimate Growth.

The first step is to calculate numbers of plots that are needed and their distribution by county, forest type, photo interpreted stand-size class, and year. The first number to estimate is that needed to satisfy accuracy standards for growth. This is done on the basis of our experience with remeasured plots in northwestern Pennsylvania, Bartlett Experimental Forest, New Hampshire, and Westveld's yield plots in Maine and elsewhere.

The calculated coefficient of variation of net growth for the 37 plots remeasured after 7 years in Pennsylvania was 83½%. The corresponding value of 48 plots remeasured after 20 years at Bartlett was 110%. While for 68 plots established by Westveld in the spruce-fir region of the northeast, it was 42% for periods that average about 20 years. The 1938 hurricane occurred during the period between measurements at Bartlett, but the plots were on a relatively small area and were fairly uniform in type and history as regards cutting and fire. It is evident we do not have a good basis for estimating "coefficient of variation" at this time. In a previous memorandum, January 27, 150% was suggested to allow for the expected greater variation in growth per plot and to allow for unforeseen contingencies.

The required sampling error, "e", was estimated assuming no change in 4,682,200 acres of commercial forest land, and an average annual growth of 44 cubic feet per acre per year. This would amount to 206,000,000 cubic feet per year, which at 5% per billion cubic feet means our allowable sampling error is just over 11%. Thus $n = c^2/e^2$ which at c = 42, 83½, 110, and 150 solves as n = 15, 58, 100, and 185 respectively. The previous recommendation of 240 plots now looks high and 100 is suggested as a first approximation, subject to revision when more data are available.

These plots are then distributed by county, major forest type, and photo stand-size class in accordance with the area data previously cited. Numbers of plots by these classes are shown in table 4. Specific plots will be selected by sorting the 912 ground plots by county, major forest type, and photo stand-size class. Then from the ground plots in each of these subclasses, the indicated number of plots will be randomly drawn. For each subclass used, an alternate plot will be drawn for use if a plot cannot be relocated or if there has been a change in land use to some non forest category. Plots affected by fire, wind, or cutting are retained in the sample.

After these plots have been remeasured, their data will be used to verify the foregoing estimates. If sample size should be increased, a new distribution of remeasured plots should be calculated and additional plots would be drawn and remeasured as needed to meet desired accuracy.

2. How Many New Plots to Estimate Inventory Volume.

The next problem is to calculate how many plots are needed to obtain current inventory volume with acceptable accuracy. This calculation is made using the formulae previously presented as follows:

Estimates of $\bar{y}_i$ and s_{y_i} were made to carry through this illustration. The range in strata means was reduced and the variance within strata was increased. When data from remeasured plots are available, we shall use calculated means and variances. From the assumed data $s^2_{y}{}'$ was estimated as 600 and $\bar{y}'$ as 900. With no change in forest area total volume in cubic feet would be 4,682,200 (900) = 4,213,980,000 cubic feet.

Thus $e^2 = \left(\frac{5}{100}\right)^2 \left(\frac{1,000,000,000}{4,213,980,000}\right) = \frac{5.9326...}{10,000}$

and $s^2_y = \frac{5.9326...(900)^2}{10,000} = (5.9326...)(81) = 481$

and the allowable error of the second estimate is given by:

$s^2_{y_2} = \frac{600\ (481)}{600-481} = \frac{288,600}{119} = 2,425$

Then numbers of plots are given by the formulae of appendix A. Assume $A = 45$; $B = 0.25$; $a = 400$; $b = 600$ $\sqrt{AB} = 3.354$. Then $a^2 = 160,000$ and $b^2 = 360,000$ and $n = \frac{400(400\ (45) + 600\ (3.354))}{45\ (2,425)} = 73.4...$new ground plots

and $N = \frac{74(600^2)}{74\ (2,425)-(400^2)} = 1,370$ photo plots.

In practice, of course these numbers of plots would be calculated from the actual data of remeasured plots and appropriate experience with A, B, a, and b.

3. How Many Plots Needed for Timber Cut.

The next problem is to calculate how many plots are needed to obtain timber cut with acceptable accuracy. We again have to assume numbers that would be available if we were using the method. These calculations too are based on the formulae used above, but are shown in more detail below:

Table 1 calculation of numbers of plots needed for timber cut.

Cutting class	P_i	$\overline{X}_i$	S_i	$\overline{X}_i - \overline{X}$	$(\overline{X}_i - \overline{X})^2$	$P_i S_i$	$\frac{nP_i S_i}{\sum P_i S_i}$
A	75	25	60	-395	156,025	45	15
B	10	1000	1400	580	336,400	140	45
C	15	2000	3100	1,580	2,496,400	465	150
Total	100					650	210

$\overline{X} = P_i\overline{X}_i = 418.75$ used as 420; $P_i(\overline{X}_i - \overline{X})^2 = 525,118.75$

Annual cut $= 420(4,682,200) = 196,652,400$

$$e^2 = \left(\frac{5}{100}\right)^2 \left(\frac{1,000,000,000}{196,652,400}\right) = 0.01271278663$$

$$s_e^2 = (0.01271278663)(418.75)^2 = 2229.206999\underline{3}\ldots$$

$$n = \frac{650(650(15) + 1.28\sqrt{525118.75})}{15(2229.2\ldots) = 33,438} = \frac{6940409.45}{33,438} = 207.56 \text{ ground plots}$$

$$N = \frac{210(525,120)}{210(2,229) - 650^2} = \frac{110,275,200}{45,590} = 2418.8 \text{ photo plots}$$

Thus our calculated numbers of plots for timber cut at 210 and 2,420 respectively are greater than the numbers needed for growth and inventory and constitute our best present estimate of number of plots to use.

As the major element of cost has been just getting on the plots, all trees as well as all stumps would be tallied. Thus all remeasured plots would serve as: growth plots, the basis for regression for current inventory, area data by ownership class, and in the estimation of timber cut. In like manner all new plots would serve twice: in the second estimate of current volume and in the estimation of timber cut. Furthermore, all plots selected for photo interpretation to stratify timber cut would also serve to stratify current inventory volume.

C. Doing the Job.

The above numbers of plots have been calculated as estimate of the numbers required to meet manual standards of accuracy. First, we must select these plots in a manner that should give us unbiased estimates of the various means and variances. We would like to retain the 912 ground plots of initial survey as a part of our fixed sample of photo plots to be able to continue to use data from the initial survey in later estimates. These 912 plots are not a random sample of the 15,189 initial photo plots, however, as they were selected under optimum allocation. This difficulty may be resolved by using a probability sample from the 15,189 initial plots or by new photo interpretation of perhaps 5,000 plots from which a probability sample is drawn which would include the 912 initial ground plots. The first alternative is more direct and straight forward but we may be compelled to use the other if we cannot accurately relocate all of the initial photo plots.

In describing how we would apply the method in New Hampshire we assume we can relocate all photo plots. Then the ground plots of initial survey would provide 912 of the required 2,420 photo plots. The remainder, 2,420-912 =1,508, would be drawn from 15,189-912 =14,277 initial photo plots so that the 2,420 photo plots would be a probability sample (with proportional allocation) for the state. This would be done by calculating the proportional distribution of 2,420 plots and obtaining the actual distribution of the 912 ground plots by county, photo stand-size, and major forest type. Differences in numbers of plots by these subclasses would be the numbers to draw in a stratified random manner from the 14,277 initial photo plots.

A subsample of 100 plots has been drawn from the 912 for remeasurement this year. These are proportional to the estimated distribution of commercial forest area in 1948 by county, photo stand-size, and major forest type. Analysis of these data is expected to show whether or not more plots should be remeasured to meet accuracy standards of net growth. If so, these plots would be drawn so that the new total would also be a proportional sample.

The new ground plots which are to be taken will be drawn from the 1,508 photo plots using optimum allocation for volume. There will be somewhat more than the calculated 110 plots because of varying requirements in numbers of plots by subclasses between inventory and timber cut. In this illustration, we have used 150 as the number of new ground plots.

There is a logical order to putting this proposed system of perpetual forest survey in operation: remeasure the plots needed for growth first to be able to more accurately determine some of the key quantities we have been guessing at; recompute the numbers of plots shown above; complete the remeasurement job and adjust numbers of photo and new ground plots as needed; do the photo interpretation job and establish the new ground plots.

In doing this, there is also a problem of timing. We should try to obtain a new series of survey estimates for New Hampshire as of January 1, 1958 and another ten years later. We expect to remeasure 100 plots there this year. Suppose that number is adequate for our needs and that there is no revision in the other numbers. That would leave us the photo interpretation of 2,420 plots and 150 new ground plots to pick up before growth starts in 1958.

Then we would want to plan procurement of the data needed for the 1968 report. First, we would use available data and experience to estimate numbers of plots to remeasure, establish, and photo interpret. The photo interpretation could not be done until new photographs were available about 1963. Assume no change in the estimated number of ground plots at 250; these we would distribute by years as well as by county, major forest type, and photo volume class. Area distribution would be proportional to the area of the class, as mentioned earlier. The distribution by years would be done to obtain approximately equal numbers by years and to minimize administrative problems as there may be opportunity.

We would also seek to build up a good representation of remeasured plots in the various intervals between measurements up to about fifteen years. Measurement after one year may be undesirable if measurement errors are large in relation to growth.

The further steps of compiling the data we expect to collect in New Hampshire are omitted in this illustration as there would be nothing new.

IV. CONCLUSION.

A method of forest survey has been proposed here that is expected to increase efficiency, improve morale, and provide better data that can be more widely used. It is based upon a coordinated design for obtaining the three major elements of inventory volume, net growth, and timber cut. The design rests upon a permanent sample of photographs with new coverage at intervals of about ten years. These photo plots are supplemented by two kinds of ground plots: remeasured and new. Eventually some plots would be remeasured and some new plots would be established throughout the northeast every year. In the meantime a period of transition would be required to make the changeover as smooth as may be. The field job would be done with men attached to the various research centers with assistance from the director's staff. The method has been illustrated by theoretical application to New Hampshire, the first state we completed in initial survey.

This method has been proposed to meet the anticipated problems of resurvey. We expect troubles to develop when we try to use it and we recognize that it may not be best for all of you. We hope you find it interesting and helpful. Your comments, criticisms, and suggestions will be welcome.

FIGURE 1. DIAGRAM OF SAMPLING DESIGN

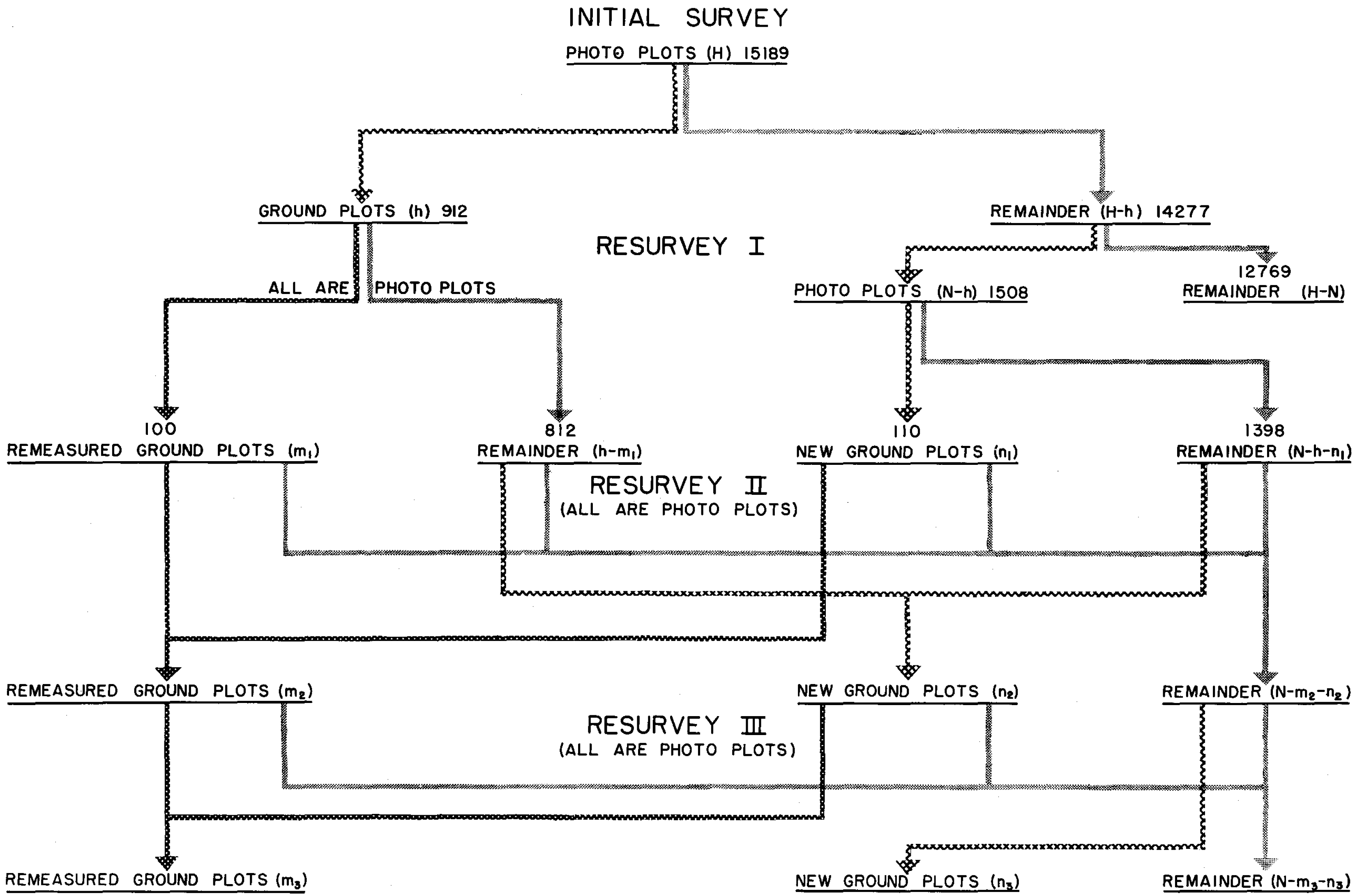


FIGURE 2. ESTIMATION OF REQUIRED DATA

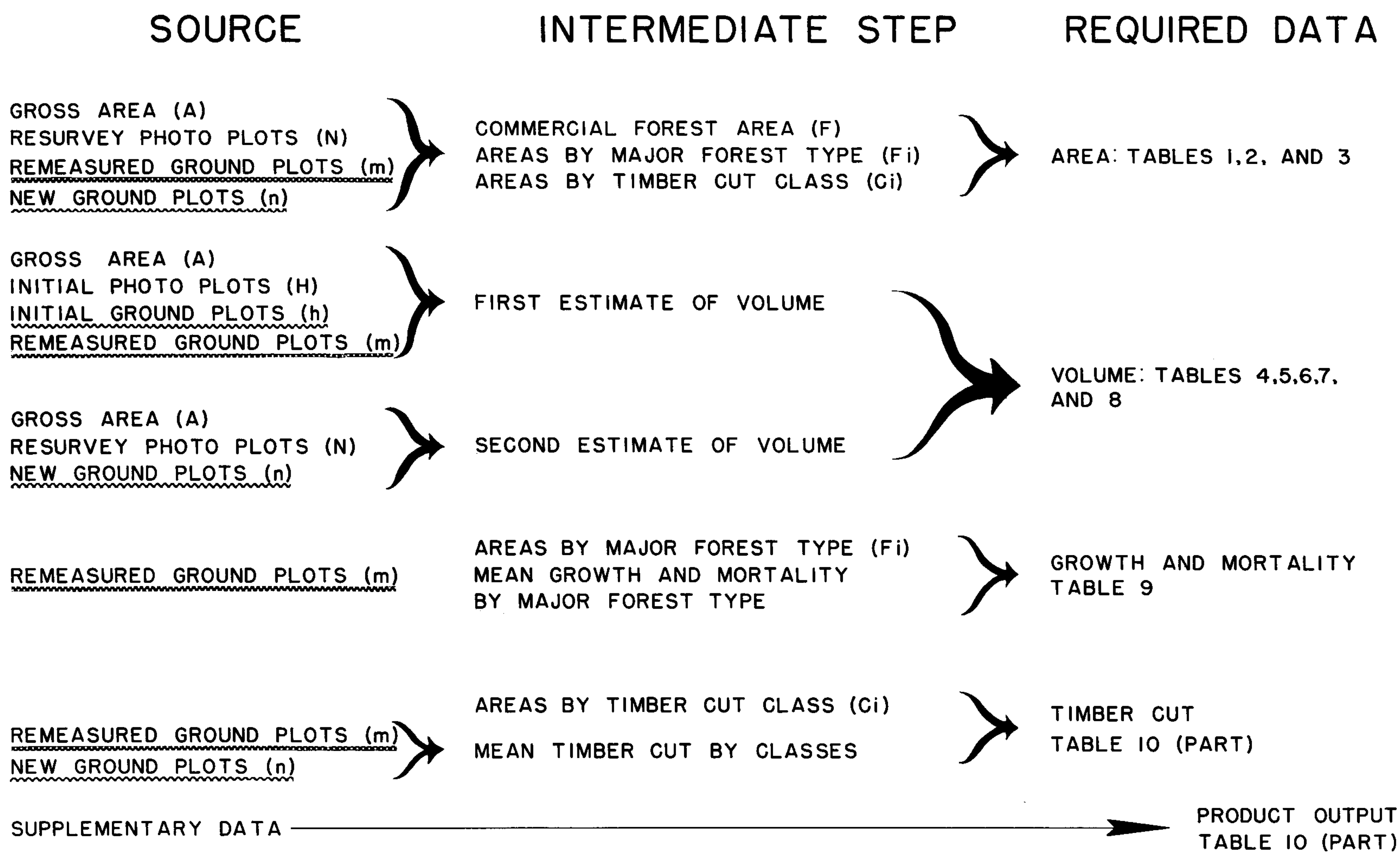
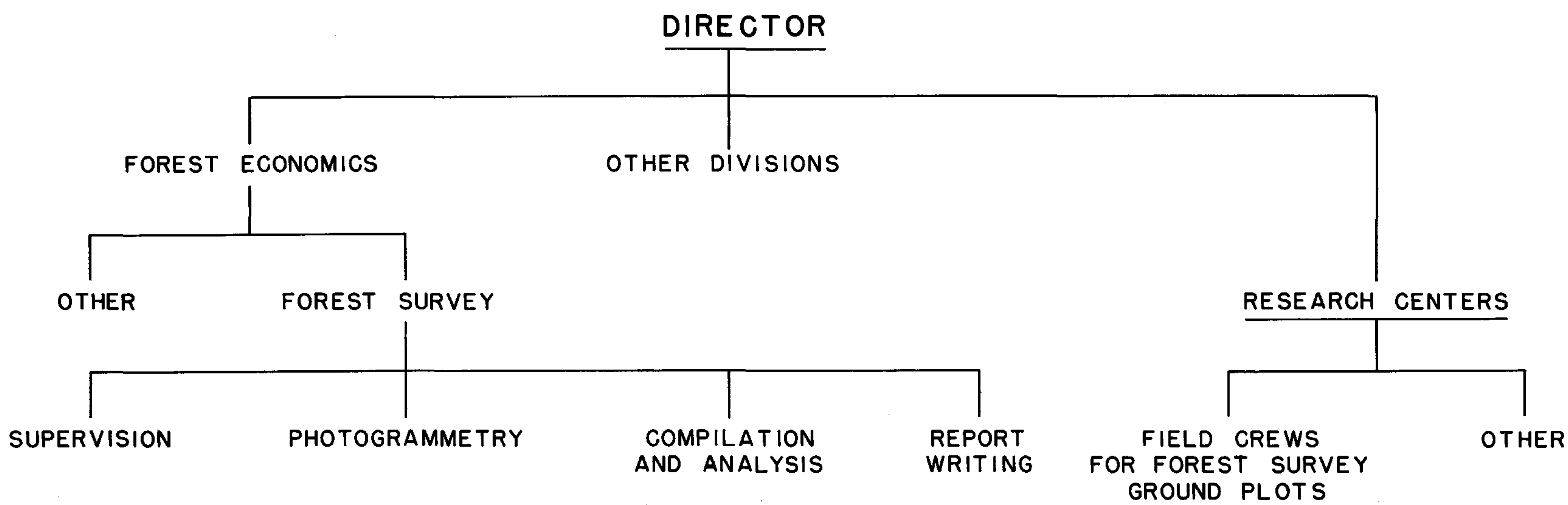


FIGURE 3

ORGANIZATION AND RESPONSIBILITY

ORGANIZATION:



RESPONSIBILITIES:

STEPS	UPPER DARBY		RESEARCH CENTERS
	FOREST SURVEY	OTHER	
LEADERSHIP	✓		
DEVELOP OVERALL DESIGN	✓	✓	
NUMBER OF PLOTS BY CLASSES, YEARS, AND COUNTIES	✓		
ARRANGE FOR PHOTOGRAPHS	✓		
PHOTOGRAPH INTERPRETATION	✓		
TRAIN AND INSPECT FIELD CREWS	✓		✓
SCHEDULE FIELD CREWS	✓		✓
PROGRESS REPORTS	✓		✓
COMPILE AND ANALYZE DATA	✓		
PREPARE REQUIRED REPORTS	✓		✓

FIGURE 4

FORMULAE USED

1. NEW GROUND PLOTS: $$n = \frac{\Sigma p_i s_i \left\{ A \Sigma p_i s_i + \sqrt{AB \Sigma p_i s_i (\bar{y}_{2i} - \bar{y}_2)^2} \right\}}{A s^2_{\bar{y}_2}}$$

2. NEW PHOTO PLOTS: $$N = \frac{n \Sigma p_i (\bar{y}_{2i} - \bar{y}_2)^2}{n s^2_{\bar{y}_2} - (\Sigma p_i s_i)^2}$$

3. REMEASURED GROUND PLOTS: $$m = \frac{c^2}{e^2}$$

4. SAMPLING ERROR OF CURRENT VOLUME: $$s^2_{\bar{y}} = \frac{s^2_{\bar{y}_1} s^2_{\bar{y}_2}}{s^2_{\bar{y}_1} + s^2_{\bar{y}_2}}$$

5. SAMPLING ERROR OF SECOND ESTIMATE REQUIRED: $$s^2_{\bar{y}_2} = \frac{s^2_{\bar{y}_1} s^2_{\bar{y}}}{s^2_{\bar{y}_1} - s^2_{\bar{y}}}$$

6. SAMPLING ERROR OF FIRST ESTIMATE:

$$s^2_{\bar{y}_1} = \frac{(\Sigma p_{1i} s'_{1i})^2}{h} + \frac{\Sigma p_{1i} (\bar{y}_{1i} - \bar{y}_1)^2}{H}$$

WHERE $$(s'_{1i})^2 = \left[\frac{(1 - r^2)(m_i - 1)}{m_i} \left\{ 1 + \frac{h_i - m_i}{h_i (m_i - 3)} \right\} - \frac{1 + (m_i - 1) r^2}{h_i} \right] \frac{s^2_{y_{1i}}}{m_i - 2}$$

7. SAMPLING ERROR OF SECOND ESTIMATE: $$s^2_{\bar{y}_2} = \frac{(\Sigma p_{2i} s_{2i})^2}{n} + \frac{\Sigma p_{2i} (\bar{y}_{2i} - \bar{y}_2)^2}{N}$$

8. NUMBER OF GROUND PLOTS IN iTH STRATUM: UNDER OPTIMUM ALLOCATION $$n_i = \left(\frac{p_i s_i}{\Sigma p_i s_i} \right) n$$

9. WEIGHTED AVERAGE: $$\bar{Y} = \frac{s^2_{\bar{Y}_2} \bar{Y}_1 + s^2_{\bar{Y}_1} \bar{Y}_2}{s^2_{\bar{Y}_1} + s^2_{\bar{Y}_2}}$$

FIGURE 5

DIAGRAM SHOWING GROWTH AND CUT IN RELATION TO INVENTORY VOLUME

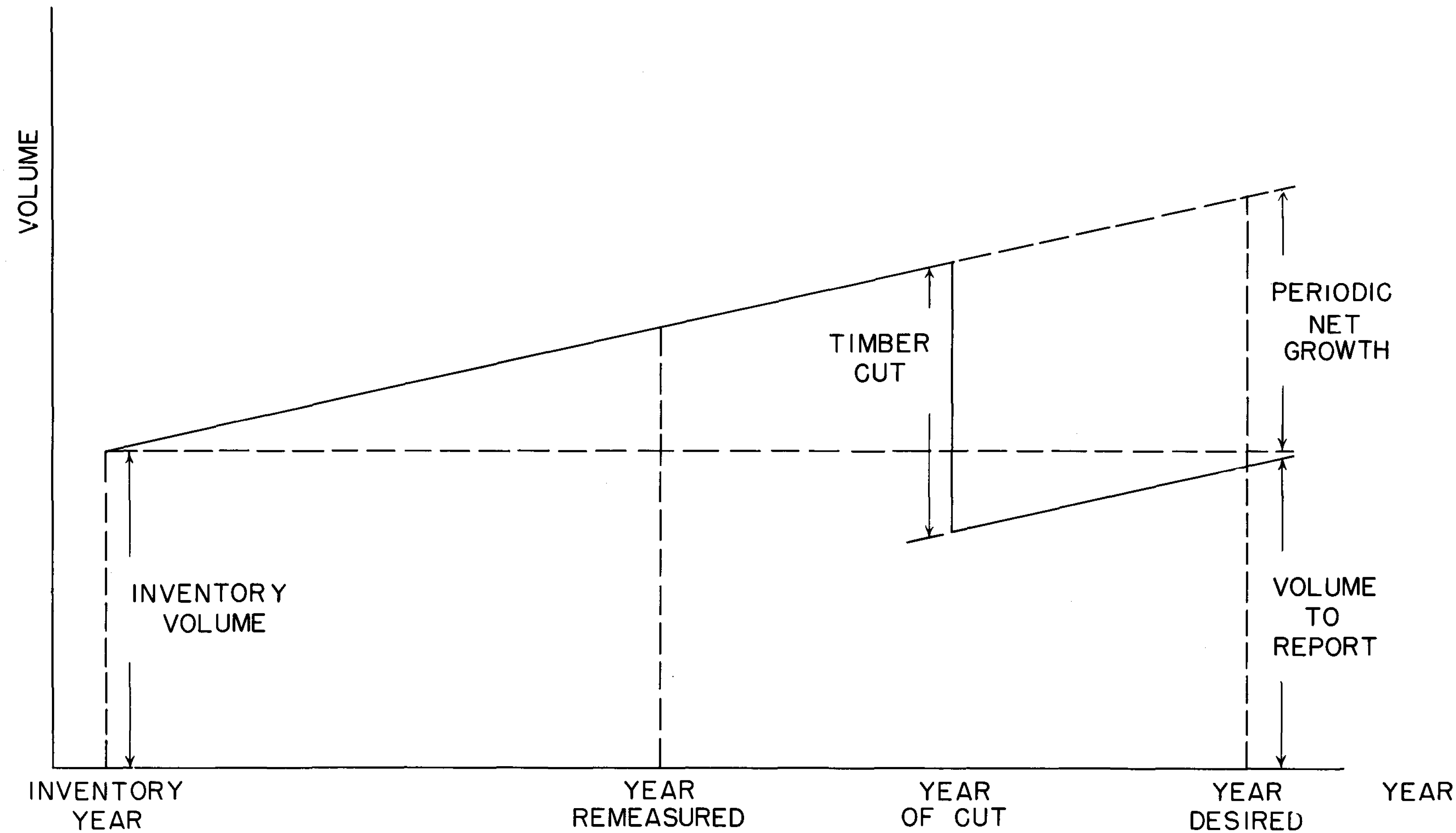


TABLE I

DISTRIBUTION OF COMMERCIAL FOREST AREA

NEW HAMPSHIRE-1948

MAJOR FOREST TYPE	COMMERCIAL FOREST LAND					
	STAND SIZE CLASS					
	1 AND 2	3	4 AND 5	6	7 AND 8	TOTAL
	NUMBERS OF PHOTO PLOTS (H IN THIS ILLUSTRATION)					
WHITE PINE	700	1,170	929	255	470	3,524
SPRUCE-FIR	209	413	755	118	103	1,598
NORTHERN HARDWOODS	609	1,611	2,639	611	723	6,193
ASPEN-BIRCH	12	33	245	363	350	1,003
TOTAL	1,530	3,227	4,568	1,347	1,646	12,318
	PROPORTION TIMES 10,000					
WHITE PINE	568	950	754	207	382	2,861
SPRUCE-FIR	170	335	613	96	83	1,297
NORTHERN HARDWOODS	494	1,308	2,142	496	588	5,028
ASPEN-BIRCH	10	27	199	295	283	814
TOTAL	1,242	2,620	3,708	1,094	1,336	10,000
	AREA IN THOUSANDS OF ACRES					
WHITE PINE	266.1	444.6	352.9	96.9	178.9	1,339.4
SPRUCE-FIR	79.6	157.2	286.8	44.8	38.9	607.3
NORTHERN HARDWOODS	231.2	612.5	1,002.7	232.4	275.4	2,354.2
ASPEN-BIRCH	4.5	12.6	93.6	138.2	132.4	381.3
TOTAL	581.4	1,226.9	1,736.0	512.3	625.6	4,682.2

TABLE 2

AREA BY STAND SIZE CLASS

STATE ____________ MAJOR FOREST TYPE ___________

	PHOTO		STAND SIZE CLASS												
VOLUME CLASS	NO. OF PLOTS	PROPORTION	1		2		3	4	5	6	7	8	9	0	TOTAL
			NO. OF PLOTS	PROP.											
1	N_1	P_1	n_{11}	p_{11}	n_{12}	p_{12}								$n_{10} p_{10}$	n_1
2	N_2	P_2	n_{21}	p_{21}	n_{22}	p_{22}									
3															
4															
5															
6															
7															
8															
9															
0	N_0	P_0													
TOTAL	N	1	Σn_{j1}	Σp_{j1}											n

TABLE 3 **DISTRIBUTION OF GROUND PLOTS TO ESTIMATE TIMBER CUT**

TIMBER CUT CLASS	PHOTO VOLUME CLASS								
	1	2	3	4	5	6	7	8	TOTAL
	PROPORTION OF COMMERCIAL FOREST AREA								
A									
B									
C									
D									
TOTAL									1

TIMBER CUT CLASS	PHOTO VOLUME CLASS								
	1	2	3	4	5	6	7	8	TOTAL
	NUMBERS OF GROUND PLOTS								
A n_{ij}									
B n_{ij}									
C n_{ij}									C_C
C c_{ij}									C_D
D c_{ij}									
TOTAL	n_1	n_2	n_3						

TABLE 4

NUMBERS OF REMEASURED PLOTS BY COUNTY, MAJOR FOREST TYPE, AND PHOTO STAND CLASS

NEW HAMPSHIRE 1956

MAJOR FOREST TYPE	PHOTO STAND CLASS (1948)						PHOTO STAND CLASS (1948)					
	1 AND 2	3	4 AND 5	6	7 AND 8	TOTAL	1 AND 2	3	4 AND 5	6	7 AND 8	TOTAL
	BELKNAP-MERRIMAC						CARROL					
WHITE PINE	2	3	2	1	1	9	1	1				2
SPRUCE-FIR						0			1			1
NORTHERN HARDWOODS		1	3	1		5	2	3	1		1	7
ASPEN-BIRCH					1	1				1		1
TOTAL	2	4	5	2	2	15	3	4	2	1	1	11
	CHESHIRE-SULLIVAN						COOS					
WHITE PINE	1	1	2		1	5						0
SPRUCE-FIR		1				1	1	2	3		1	7
NORTHERN HARDWOODS		1	4	2	1	8	2	4	4		2	12
ASPEN-BIRCH						0			1	1		2
TOTAL	1	3	6	2	2	14	3	6	8	1	3	21
	GRAFTON						HILLSBOROUGH					
WHITE PINE		1	1		1	3	1	2	1			4
SPRUCE-FIR	1		2	1		4						0
NORTHERN HARDWOODS	1	3	4		2	10			2	1		3
ASPEN-BIRCH			1	1		2					2	2
TOTAL	2	4	8	2	3	19	1	2	3	1	2	9
	ROCKINGHAM-STRAFFORD						STATE TOTAL					
WHITE PINE	1	1	2	1	1	6	6	9	8	2	4	29
SPRUCE-FIR						0	2	3	6	1	1	13
NORTHERN HARDWOODS		1	3	1		5	5	13	21	5	6	50
ASPEN-BIRCH						0			2	3	3	8
TOTAL	1	2	5	2	1	11	13	25	37	11	14	100

TABLE 5

DISTRIBUTION OF REMEASURED PLOTS BY MAJOR FOREST TYPE, PHOTO VOLUME CLASS, AND YEAR

COOS COUNTY, NEW HAMPSHIRE

MAJOR FOREST TYPE	PHOTO VOLUME CLASS: 1 AND 2	3	4 AND 5	6	7 AND 8	TOTAL (NO. PLOTS)
	(YEAR OF MEASUREMENT WITHIN 10 YEAR PERIOD)					
	ALTERNATIVE I (ANNUAL)					
WHITE PINE						0
SPRUCE-FIR	6	3-5	2-4-8		7	7
NORTHERN HARDWOODS	2-9	5-6-8-10	1-4-7-9	1	10	12
ASPEN-BIRCH			2	3		2
TOTAL (NO. PLOTS)	3	6	8	2	2	21
	ALTERNATIVE II (BIENNIAL)					
WHITE PINE						
SPRUCE-FIR	6	4-6	2-4-8		8	7
NORTHERN HARDWOODS	2-10	6-6-8-10	2-4-8-10	2	10	12
ASPEN-BIRCH			2	4		2
TOTAL (NO. PLOTS)	3	6	8	2	2	21

BY YEARS

YEAR	I	II	YEAR	I	II
1	2		7	2	
2	3	5	8	2	4
3	2		9	2	
4	2	4	10	2	4
5	2				
6	2	4	TOTAL	21	21

CALCULATION OF SAMPLING ERROR OF FIRST ESTIMATE

CLASS	P_i	$\bar{y}'_i$	S'_i	$\bar{y}'_i - \bar{y}'$	$(\bar{y}'_i - \bar{y}')^2$
1 AND 2	1,242	1,581	1,026	332	110,224
3	2,620	1,449	828	200	40,000
4 AND 5	3,708	1,283	742	34	1,156
6	1,094	917	603	−332	110,224
7 AND 8	1,336	728	311	−521	271,441
TOTAL	10,000				

$\bar{y}' = \Sigma P_i \bar{y}'_i = 1249 \quad \Sigma P_i S'_i = 727 \quad \Sigma P_i (\bar{y}'_i - \bar{y}') = 72921$

$$S^2_{\bar{y}'} = \frac{(727)^2}{890} + \frac{72921}{15{,}139} = 593.85\ldots + 4.8\underline{2}\ldots = 598.6\underline{7}\ldots$$

890 IS NUMBER OF FOREST GROUND PLOTS

15,139 IS NUMBER OF PHOTO PLOTS